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All About Space

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USER MANUAL

**NASA'S HUBBLE SPACE
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Issue 129

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Instant expert

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It might be the most familiar place to us, but our strange solar neighbourhood still continues to surprise, as you'll discover in this issue of **All About Space**. This month we have 25 weird and wonderful facts about our Solar System - and everything that fills it - to blow your mind. From its sheer size to the mysterious volcanoes of Jupiter's moon Io, turn to page 14 to uncover

something you didn't know about our corner of the universe.

Elsewhere in the magazine, we offer up some top tips and tricks to getting a variety of stunning images and great views of the night sky with as little fuss as possible. If you've ever wanted to get the very best sights of the Andromeda Galaxy, shoot the planets with your smartphone, shoot star trails and learn how to star hop, then you have come to the right place. We have plenty of tutorials on offer, so head over to page 54 to get started. You don't have to spend a fortune for great results. The advice doesn't stop there, as our team of experts offers advice on the best eyepieces to use with your telescope and the very best space products to snap up in the shops today.

Enjoy the issue - I'll look forward to seeing you for our big 130th! And don't forget to claim your free copies of our Solar System eBooks on page 79.

GEMMA LAVENDER

Content Director

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Mysterious magnetic filaments have been found at the heart of the Milky Way, but astronomers are still trying to discover their origin

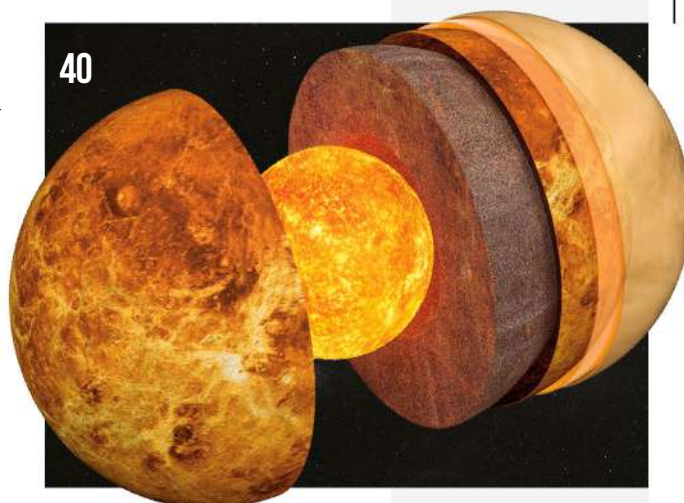
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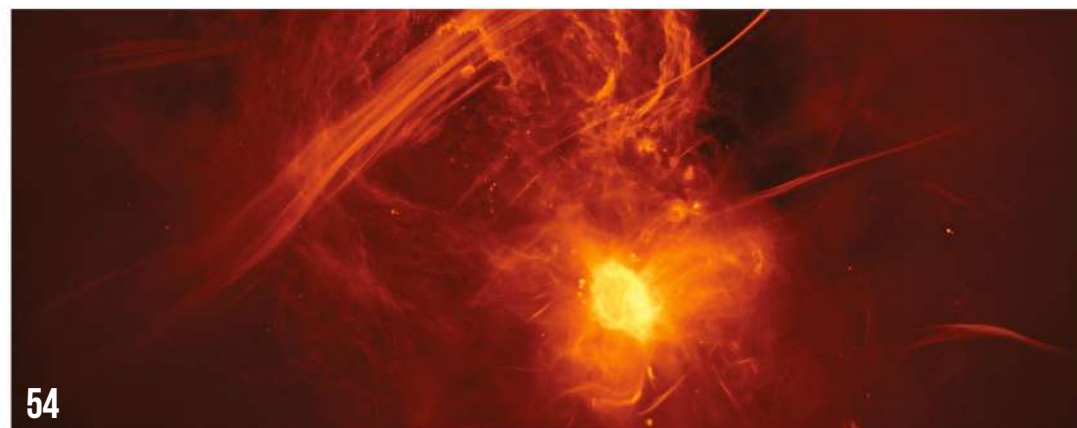
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**WORTH OVER
£600**

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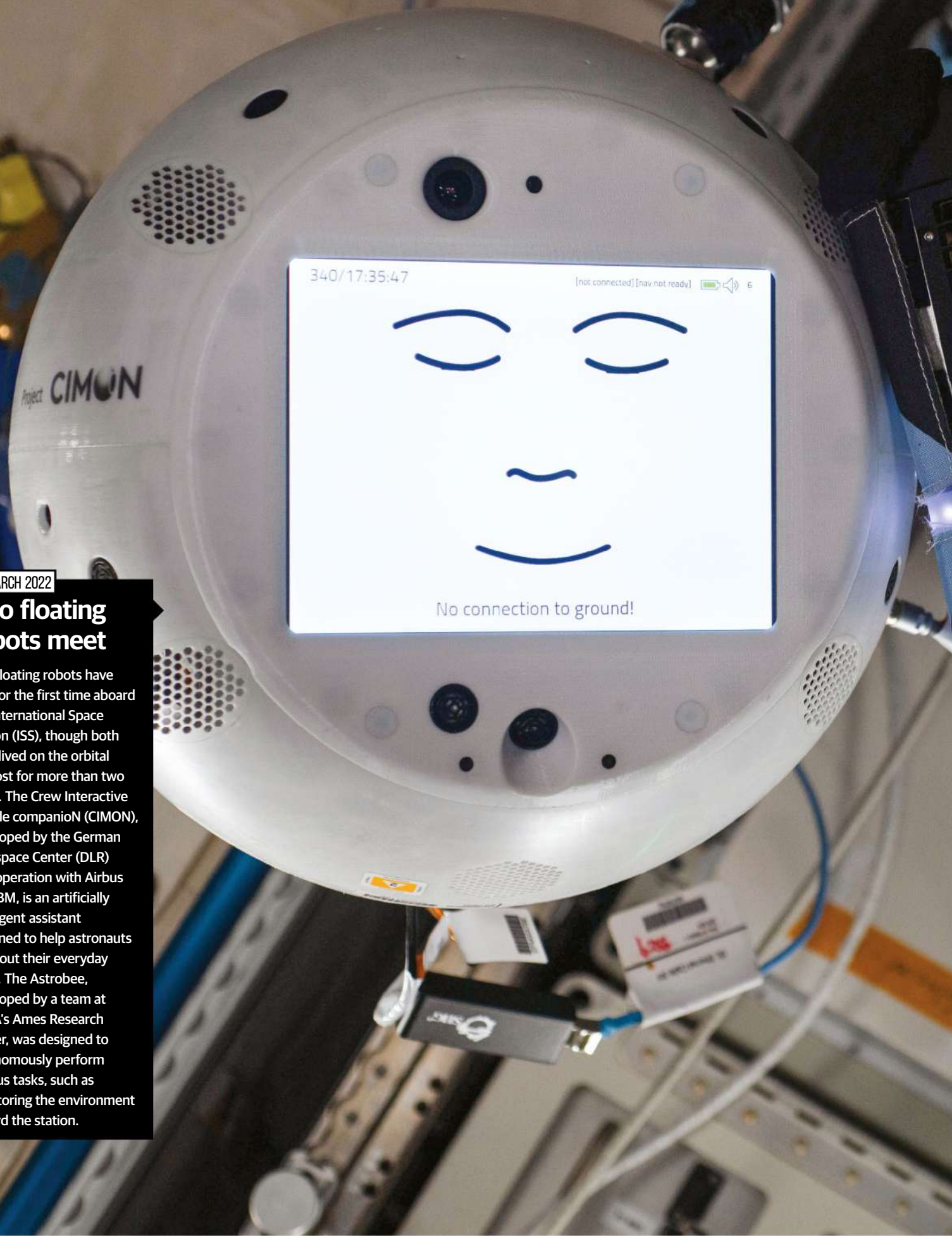
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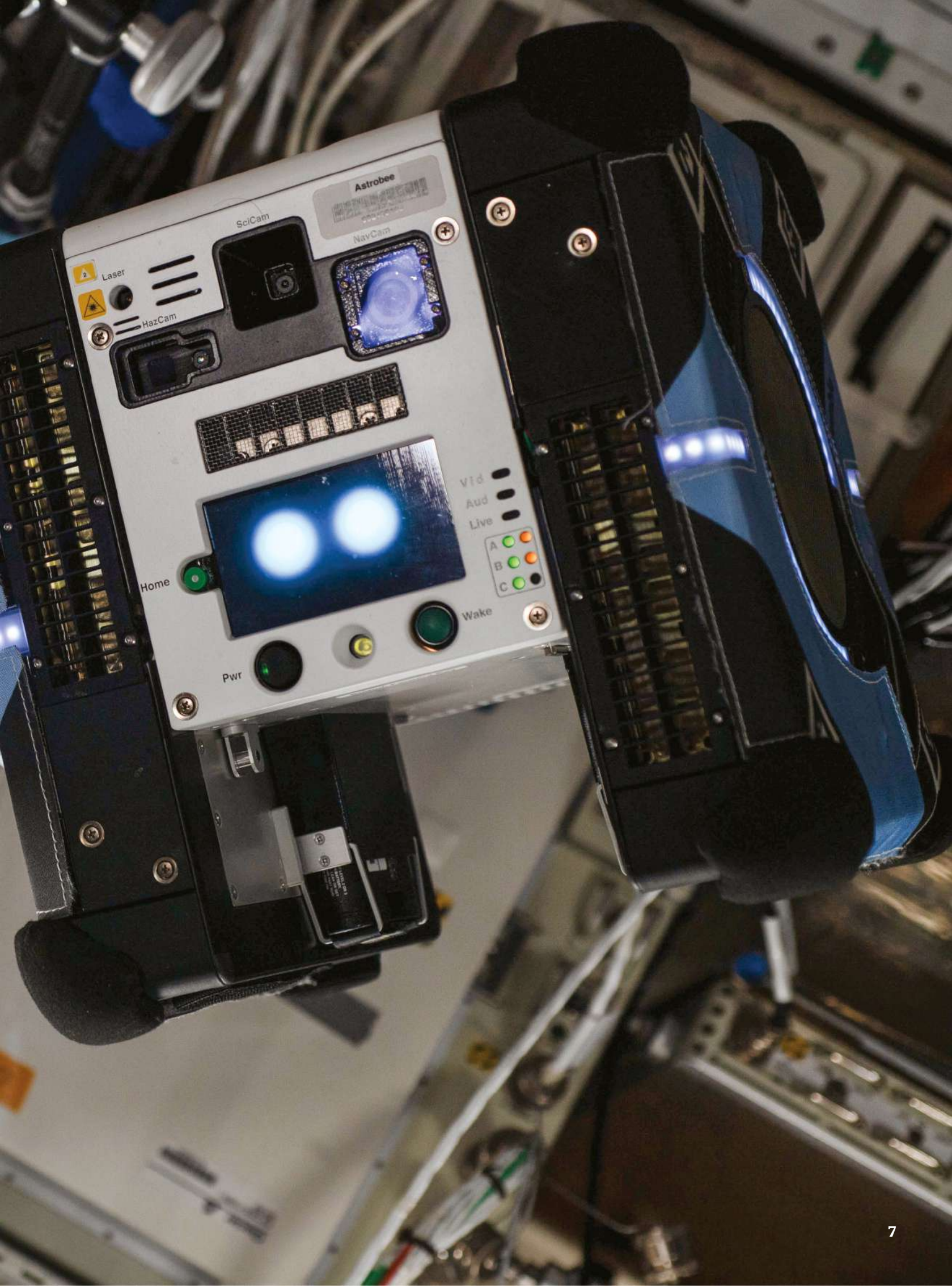
22 MARCH 2022

Two floating robots meet

Two floating robots have met for the first time aboard the International Space Station (ISS), though both have lived on the orbital outpost for more than two years. The Crew Interactive MOBILE companion (CIMON), developed by the German Aerospace Center (DLR) in cooperation with Airbus and IBM, is an artificially intelligent assistant designed to help astronauts go about their everyday tasks. The Astrobee, developed by a team at NASA's Ames Research Center, was designed to autonomously perform various tasks, such as monitoring the environment aboard the station.

©NASA









21 MARCH 2022

Hubble spies a spiral

This image of spiral galaxy NGC 4571, approximately 60 million light years from Earth, is part of a partnership between Hubble and other telescopes to provide more information about huge collections of stars. The galaxy is part of the Virgo Cluster of galaxies that contains more than 1,000 members. The cluster also encompasses the Local Group, which is the set of galaxies near to and including our own galaxy, the Milky Way. Astronomers are not only interested in looking at individual galaxies, but also examining them in context of their environments to learn more about how stars are formed and how galaxies evolve over billions of years.

© ESA/Hubble & NASA

26 JANUARY 2022

Moon with a view

The Moon, NASA's target for its Artemis program, shines as a tantalising destination in this photo taken from the International Space Station. This shot was captured by a member of the station's current Expedition 66 crew - which comprises of NASA astronauts Raja Chari, Thomas Marshburn, Kayla Barron and Mark Vande Hei; the European Space Agency's Matthias Maurer; Roscosmos' Anton Shkaplerov and Pyotr Dubrov - shows a waning gibbous Moon phase as the Moon shines above a brilliant Earth. The station was flying about 437 kilometres (272 miles) above the Atlantic Ocean off the coast of southern Argentina when this shot was captured.

© NASA



WEBB TAKES ITS FIRST VIEW OF THE COSMOS

Words by Tereza Pultarova

The James Webb Space Telescope's main mirror is fully aligned and is performing even better than it was designed to. The 6.5-metre (21.3-foot) mirror, composed of 18 hexagonal segments, had to travel to space folded up. Aligning it into one smooth reflecting surface was one of the main tasks that the Webb control team has had to tackle since the giant telescope's launch on 25 December. The alignment process, which involved fine-tuning the positions and inclinations of the 18 segments with nanometre-scale precision, has now been completed. And the James Webb Space Telescope mission - the most complex and most expensive observatory ever launched - is already producing images that take scientists' breath away.

"The telescope's performance so far is everything that we dared to hope," Jane Rigby, Webb operations project scientist at the NASA Goddard Space Flight Center in Maryland, said. "The engineering images that we saw today are as sharp and as crisp as the images that Hubble can take, but are at a wavelength of light that is totally invisible to Hubble. This is making the invisible universe snap into very sharp focus."

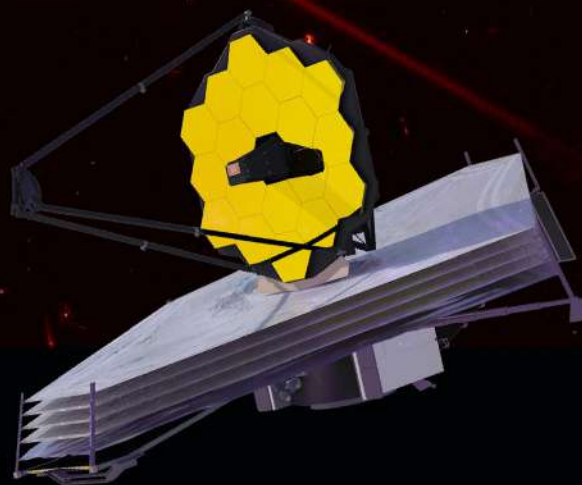
When the mirror alignment process started in early January, the ground team pointed the telescope at HD 84406, what the scientists described as a very 'boring star' in our Milky Way. The star, 100 times fainter than what can be seen with the naked eye, was

chosen not for its scientific significance but purely for its brightness and location.

At the beginning of the alignment process, the telescope was delivering 18 individual images of the star, with each of the primary mirror segments acting as a telescope on its own. The latest image shows a brightly shining, amber-coloured star emanating streams of light across the universe. Even more interesting than the star itself, however, is its background, revealing dozens of specks and dots - each a distant galaxy that was previously out of reach.

These distant galaxies make Webb's first image a so-called deep field. Such photographs, focusing on small sections of the sky, aim to capture the most distant objects in the universe. Deep fields are a specialty of the Hubble Space Telescope, Webb's predecessor. Webb, however, is set to beat Hubble in its ability to peer into the depths of space. "There's no way that Webb can look for 2,000 seconds at any point in the sky and not get an incredibly deep field," Rigby said. "This is going to be the future from now on. Wherever we look, it's a deep field. Without even really breaking a sweat, we're seeing back in time to galaxies where we're seeing the light as it looked billions of years ago."

"THE IMAGE SHOWS AN AMBER-COLOURED STAR EMANATING STREAMS OF LIGHT ACROSS THE UNIVERSE"



Above: An image taken by Webb during its alignment process shows galaxies and stars in the background

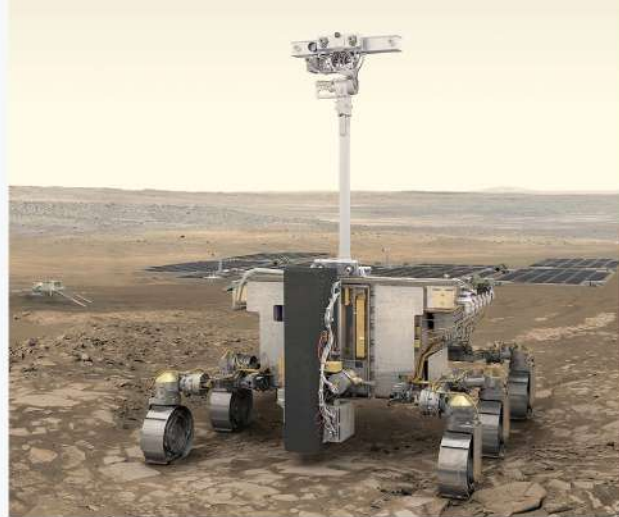
© NASA

EUROPE'S MARS ROVER IS NOW UNLIKELY TO LAUNCH BEFORE 2026 AFTER RUSSIA'S WAR ON UKRAINE

Words by Tereza Pultarova

Europe's beleaguered ExoMars rover is unlikely to launch before 2026 as the European Space Agency (ESA) ponders a path forward for the mission, including finding a new rocket, replacing Russian-built parts in cooperation with NASA or restarting its partnership with Russia in case the country's war in Ukraine ends soon. ESA representatives outlined their plans for the mission in a press conference on 17 March after officially suspending cooperation with Russia's space agency Roscosmos as a result of sanctions imposed on Russia by ESA member states.

The ExoMars rover, conceived in 2005, was scheduled to launch to Mars from the Russia-controlled Baikonur Cosmodrome in Kazakhstan on a Russian-built Proton rocket in September. "We have to do detailed studies of what this means and how the rover can arrive on the Mars surface,"



© ESA

ESA director general Josef Aschbacher said at the briefing. "We have to see what the options are in terms of Europe alone or with partners." He added that the ESA "was closely working with NASA to identify where NASA could help."

The space agency didn't rule out a possible future restart of the cooperation with Russia in case the war in Ukraine ends, an option that would come with the lowest additional price tag for the mission, which has already cost ESA member states over \$1.1 billion (£840 million). "The possibility of restarting that cooperation at some future date is available and would be compatible with the launch in 2024," David Parker, the ESA's director of human and robotic exploration, said at the same press conference. "More radical reconfigurations of the mission would lead to launches in 2026 or 2028."

Above: The ExoMars rover was scheduled to launch to Mars in September

5,000 EXOPLANETS: NASA CONFIRMS A BIG MILESTONE FOR PLANETARY SCIENCE

Words by Elizabeth Howell

Our tally of strange new worlds just reached 5,000. The milestone comes amid a surge of recent discoveries and the promise of more insights to come as NASA's James Webb Space Telescope readies for planet-gazing operations in deep space. "The 5,000-plus planets found so far include small, rocky worlds like Earth; gas giants many times larger than Jupiter and 'hot Jupiters' in scorchingly close orbits around their stars," Jet Propulsion Laboratory officials said in a statement. "There are 'super-Earths,' which are possible rocky worlds bigger than our own, and 'mini-Neptunes,' smaller versions of our system's Neptune," the officials added. "Add to the mix planets orbiting two stars at once and planets stubbornly orbiting the collapsed remnants of dead stars."

The NASA Exoplanet Archive is housed at the California Institute for Technology. To be added to the catalogue, planets must be independently confirmed by two different methods and the work must be published in a peer-reviewed journal. The first exoplanets were found in the early 1990s. While telescopes on the ground and in space have

done well to get the count to 5,000 since then, the worlds found to date are "mostly in this little bubble around our Solar System, where they are easier to find."

"Of the 5,000 exoplanets known, 4,900 are located within a few thousand light years of us," Jessie Christiansen, science lead of the NASA Exoplanet Archive, added. "And think about the fact that we're 30,000 light years from the centre of the galaxy; if you extrapolate from the little bubble around us, that means there are many more planets in our galaxy we haven't found yet - as many as 100 to 200 billion. It's mind-blowing."



© NASA

Below: In March 2022, NASA confirmed the 5,000th exoplanet discovery

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CHINA PLANS TO OPEN ITS TIANGONG SPACE STATION FOR TOURISM WITHIN A DECADE

Words by Andrew Jones

China is looking to spark interest in space tourism by opening its soon-to-be-completed space station to everyday citizens. Yang Liwei, who made history in 2003 by becoming China's first astronaut in space, told Chinese media earlier this month that people without formal astronaut training could soon visit the Tiangong space station. "It is not a matter of technology but of demand," Yang said when asked if the general public would be able to tour Tiangong. "And it can be realised within a decade as long as there is such demand."

But first China needs to complete the three-module, T-shaped space station and make it fully operational. China plans to launch six missions this year to complete Tiangong. These will be launches of two new modules, a pair of cargo supply missions and two crewed missions, Shenzhou 14 and



© Adrian Mann

Shenzhou 15. These two three-person missions are also expected to carry out the first crew handover, which will temporarily see six astronauts aboard the space station.

But Shenzhou spacecraft, which launch from Jiuquan in the Gobi Desert on an established Long March 2F rocket, won't be the only option for getting tourists into space. China is working on a reusable rocket for human spaceflight which would be capable of launching a new, larger and partially reusable crew spacecraft to the space station. The new approach would mean more people could fly to space at once.

Whereas Shenzhou spacecraft can transport only three astronauts, the new generation of crewed space transportation vehicles will be capable of carrying six to seven astronauts, Huang Kewu, a human spaceflight official with the country's main space contractor, the China Aerospace Science and Technology Corporation, said last year.

Above:
An artist's illustration of China's space station in Earth orbit

COMET LEONARD BREAKS INTO PIECES AS IT ROUNDS THE SUN

Words by Elizabeth Howell

The brightest comet of 2021 has disintegrated. Icy wanderer Comet C/2021 A1 (Leonard) fell apart during its perihelion, or closest approach to the Sun. Perihelion was projected for 3 January roughly a year after the comet's discovery. The comet's discoverer, Gregory Leonard of the Catalina Sky Survey in Tucson, said the comet's legacy was the tail structures made up of charged particles,

known as ions. The tail was subject to "spectacular outburst-induced displays" after spotting the comet on 3 January 2021, he said. "Otherworldly and astonishing are the only descriptions that come to mind when I began viewing the images being posted online by a handful of dedicated expert astrophotographers, particularly after 19 December 2021, when the comet began undergoing strong periodic outburst activity," said Leonard.

Even if the comet had survived its journey around the Sun, it would have been flung into interstellar space, never to return. But that wasn't to be. First came a false alarm in late November that the comet might be showing signs of stress. In the weeks before perihelion, however, Comet Leonard's brightness started to change every three to five days. The comet's tail began to show some complicated structure, possibly due to pieces breaking off the nucleus, revealing new areas that the Sun would then heat.

Confirmation of Leonard's breakup first came from Martin Masek on 23 February. Other observers, including the Slooh telescope in Chile, obtained images showing the comet as little more than a ghostly streak.

Left: Comet Leonard reached perihelion, its closest point to the Sun, on 3 January 2022

Right:
The latest Dragon is named Freedom



© Getty

SPACEX'S NEW DRAGON CAPSULE GETS A NAME

Words by Chelsea Gohd

SpaceX's Crew-4 mission will fly to the International Space Station (ISS) on 19 April, and the mission's Dragon capsule just got a name: Freedom. "Crew-4 will fly to the ISS in a new Dragon capsule named Freedom. The name celebrates a fundamental human right and the industry and innovation that emanate from the unencumbered human spirit," NASA astronaut Kjell Lindgren, who will command the Crew-4 mission, said on Twitter on 23 March.

Lindgren will fly alongside fellow NASA astronauts Robert Hines and Jessica Watkins, as well as European Space Agency astronaut Samantha Cristoforetti.

"Through the Commercial Crew Program, NASA and SpaceX have restored a national capability, and we honour the ingenuity and hard work of those involved. Alan Shepard flew on Freedom 7 at the dawn of human spaceflight. We are honoured to bring Freedom to a new generation!" Lindgren added in a follow-up post.

Freedom will be the fourth SpaceX Dragon capsule to carry astronauts to space. The other three, which were also named by the first crew members to ride them, are Endeavour, Resilience and Endurance.



© SPACEX

WIN



VIXEN POLARIE STAR TRACKER

Courtesy of Opticron, this month we're giving away kit to assist with your astrophotography

A compact mount platform that allows you to capture nightscapes and star images with elegance and ease, the Vixen Polarie Star Tracker allows you to capture the universe through the art of astrophotography. Ultra-light and portable, this star tracker is ideal for wide-field astroimaging. Operational on two AA batteries, the Polarie tracks the motion of the stars in order to eliminate star trails for exquisitely sharp images.

Setting up is easy and fast - the Polarie can be attached to a standard camera tripod and accepts a digital camera weighing up to 3.2 kilograms. An included compass on the Polarie Star Tracker mount makes northern alignment easy, along with a polar scope for alignment.

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To be in with a chance of winning, answer this question:

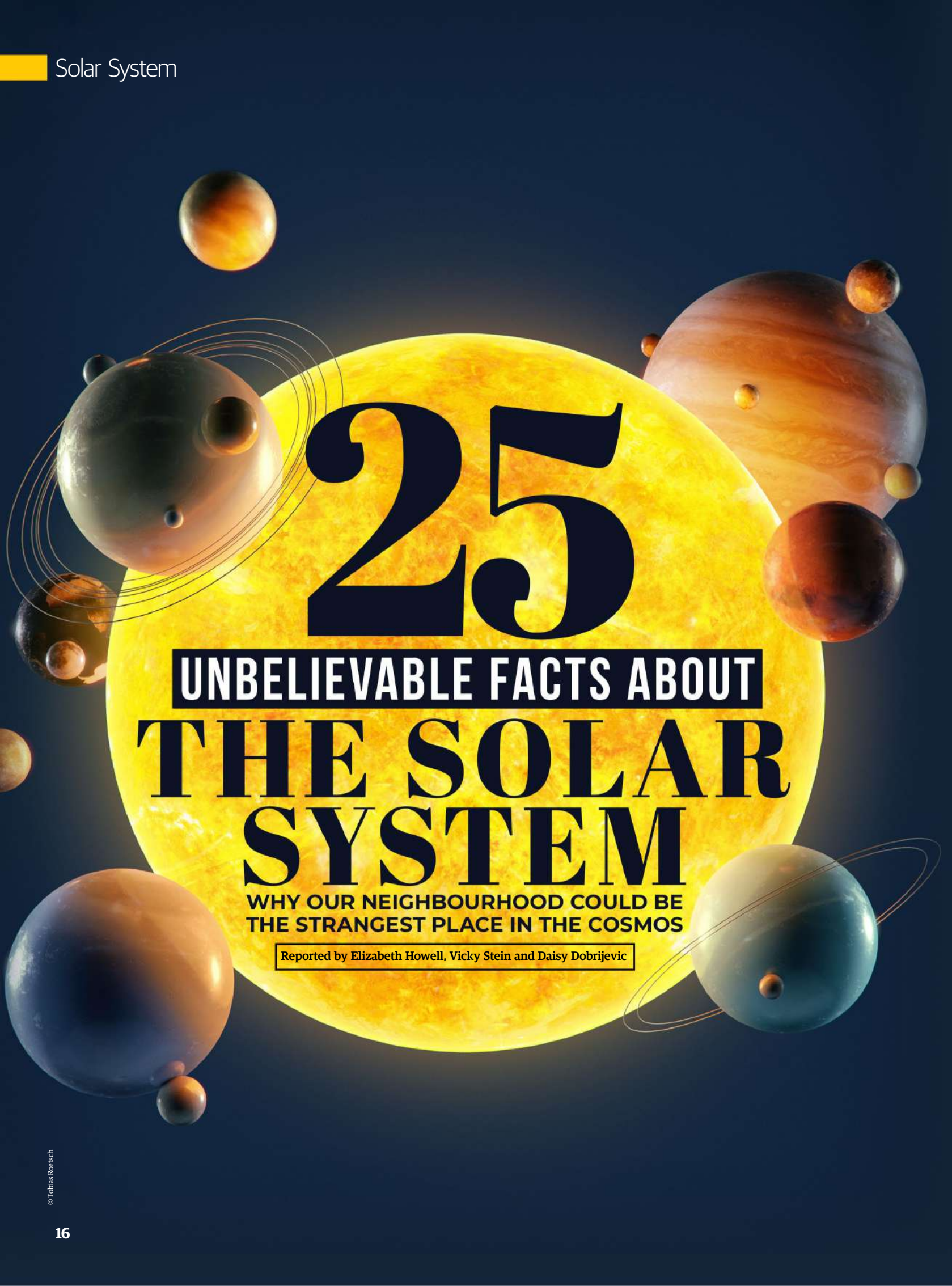
What is a star tracker used for?

- A:** To take still images of the night sky
- B:** To help stabilise your telescope
- C:** To help you choose the right eyepiece

Competition ends on 18 May 2022

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25

UNBELIEVABLE FACTS ABOUT THE SOLAR SYSTEM

WHY OUR NEIGHBOURHOOD COULD BE
THE STRANGEST PLACE IN THE COSMOS

Reported by Elizabeth Howell, Vicky Stein and Daisy Dobrijevic

1 THE SOLAR SYSTEM IS REALLY BIG

NASA's Voyager 1 spacecraft was launched in 1977. More than three decades later, in 2012 it became the first human-made object to enter interstellar space by crossing the heliopause - the edge of the heliosphere. That's the boundary beyond which most of the Sun's ejected particles and magnetic fields dissipate. "If we define our Solar System as the Sun and everything that primarily orbits the Sun, Voyager 1 will remain within the confines of the Solar System until it emerges from the Oort Cloud in another 14,000 to 28,000 years," NASA says.

"THE MOON IS BOTH MIND-BOGGLINGLY DISTANT AND INCREDIBLY CLOSE DEPENDING ON HOW YOU THINK ABOUT IT"

2 EVEN JUST OUR NEIGHBOURHOOD IS REALLY BIG

Depending on how carefully you do the calculations and how you arrange them, all of the planets in the Solar System could fit in between Earth and its Moon. The distance between Earth and the Moon varies as it orbits around us, as does the diameter of each of the planets - they're wider at their equators, so Saturn and Jupiter would have to be tilted sideways for this to work. But imagine lining them all up, pole to pole. They'd just barely squeeze in between us and our closest companion in space, blocking out the sky with their rings and gas giant bulk as they did so.

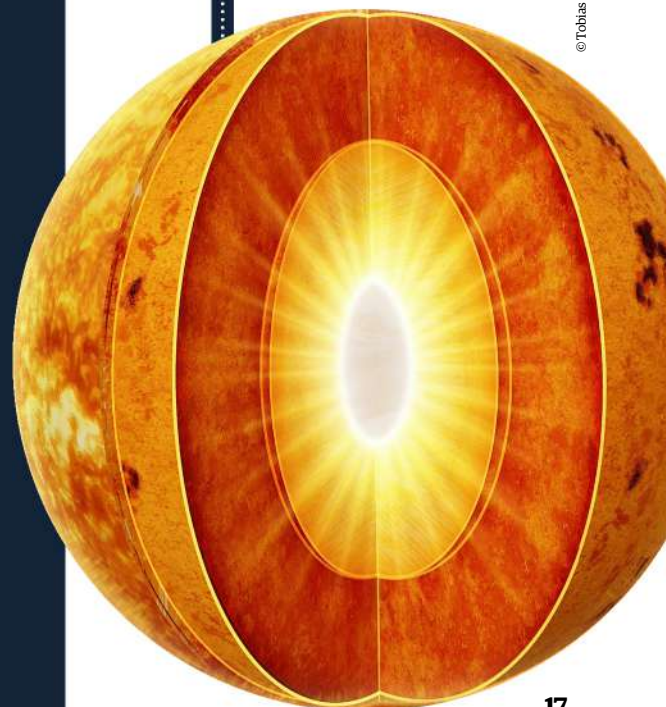
The Moon is the farthest from Earth we've ever sent humans, and it's both mind-bogglingly distant and incredibly close depending on how you think about it. Eight enormous planets could fit between here and there, and the distance from Earth to the Sun is more than 390 times the distance from Earth to the Moon. Scientists use an approximation of the Earth-Sun distance, also known as one astronomical unit, or AU, to compare distances within the Solar System. Jupiter is about 5.2 AU from the Sun, and Neptune is 30.07 AU from the Sun - around 30 times as far from the star as Earth.

3

THE SUN'S ATMOSPHERE IS HOTTER THAN ITS SURFACE

While the Sun's visible surface, the photosphere, is 5,500 degrees Celsius (10,000 degrees Fahrenheit), its upper atmosphere has temperatures in the millions of degrees. It's a large temperature differential with little explanation. NASA has several Sun-gazing spacecraft on the case, however, and they have some ideas for how the heat is generated. One is 'heat bombs', which happen when magnetic fields cross and realign in the corona. Another is when plasma waves move from the Sun's surface into the corona. With new data from the Parker Solar Probe - which recently became the first human-made object to 'touch' the Sun - coming in all the time, we're closer than ever to unlocking the mysteries at the heart of our Solar System.

© Tobias Roetsch





4

MERCURY IS STILL SHRINKING

Mercury is already the smallest planet in the Solar System, and is the second-densest after Earth. And it's only getting smaller and denser. For many years, scientists believed that Earth was the only tectonically active planet in the Solar System. But that changed after the Mercury Surface, Space Environment, Geochemistry and Ranging (MESSENGER) spacecraft did the first orbital mission at Mercury, mapping the entire planet in high definition and getting a look at the features on its cratered surface.

In 2016, data from MESSENGER revealed cliff-like landforms known as fault scarps. Because the fault scarps are relatively small, scientists can be sure that they weren't created that long ago and that the small planet is still contracting 4.5 billion years after the Solar System was formed.



5 VENUS IS SWEEPED BY POWERFUL WINDS THAT COULD HARBOUR LIFE

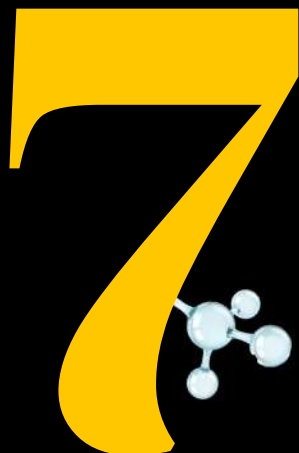
Venus is a hellish planet with a high-temperature, high-pressure environment on its surface. Bone-dry and hot enough to melt lead, it's not exactly a welcoming environment, and has probably always been inhospitable to life. When the heavily shielded Venera spacecraft from the Soviet Union landed there in the 1970s, each lasted a few minutes, or at most a few hours, before melting or being crushed beyond their ability to function.

But even above its surface, the planet has a bizarre environment. Scientists have found that its upper winds flow 50 times faster than the planet's rotation. The European Venus Express spacecraft, which orbited the planet between 2006 and 2015, tracked the winds over long periods and detected periodic variations. It also found that the hurricane-force winds appeared to be getting stronger over time. A 2020 study that thrilled many astrobiologists detected phosphine, a possible sign of decaying biological matter, high in the Venusian clouds. Could they be a sign of life? Not without sufficient water, claim follow-up studies that firmly reject the possibility of life in Venus' dry and windy atmosphere.

6 EARTH'S VAN ALLEN BELTS ARE MORE BIZARRE THAN EXPECTED

There are several bands of magnetically trapped, highly energetic charged particles surrounding our planet, known as the Van Allen belts, named after the discoverer of the phenomenon. While we've known about the belts since the dawn of the Space Age, the Van Allen Probes, launched in 2012, have provided our best ever view of them. They've uncovered quite a few surprises along the way. We now know that the belts expand and contract according to solar activity. Sometimes the belts are very distinct from one another, and sometimes they swell into one massive unit. An extra radiation belt beyond the known two was spotted in 2013. Understanding these belts helps scientists make better predictions about space weather or solar storms.

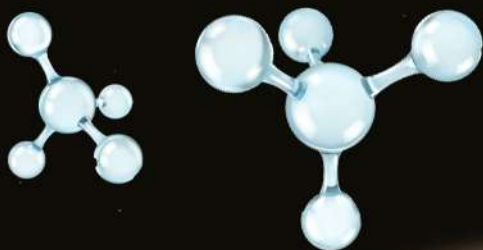




ORGANIC MOLECULES ARE EVERYWHERE

Organics are complex carbon-based molecules found in living things, but can be created by non-biological processes too. While organic molecules are common on Earth, they can be found in many other places in the Solar System too. Scientists have found organics on the surface of Comet 67P/Churyumov-Gerasimenko, for example. The discovery bolstered the case that organic molecules on Earth could have been brought to the surface from space. Organics have also been found on the surface of Mercury, on Saturn's moon Titan - giving Titan its orange colour - and on Mars.

©Getty



8 A VALLEY ON MARS COULD SWALLOW THE GRAND CANYON

At 4,000 kilometres (2,500 miles), the immense system of Martian canyons known as Valles Marineris is more than ten times as long as the Grand Canyon on Earth. Valles Marineris escaped the notice of earlier Mars spacecraft flying over other parts of the planet and was finally spotted by the global mapping mission Mariner 9 in 1971. And what a sight it was to miss - Valles Marineris could stretch from New York to Seattle. The lack of active plate tectonics on Mars makes it tough to figure out how the canyon formed. Some scientists think that a chain of volcanoes on the other side of the planet, known as Tharsis Ridge, which includes Olympus Mons, somehow bent the crust from the opposite side of Mars. That cataclysmic force activated cracks in the crust, vast amounts of subsurface water that emerged to carve away rock and glaciers that crunched new pathways into the canyon system.



©NASA

9 MARS' BIGGEST VOLCANO IS BIGGER THAN HAWAII

While Mars seems quiet now, gigantic volcanoes once dominated the surface of the planet. This includes Olympus Mons, the biggest volcano ever discovered in the Solar System. At 602 kilometres (374 miles) across, the volcano is comparable to the size of Arizona. It's 25 kilometres (16 miles) high, or triple the height of Mount Everest, the tallest mountain on Earth. By volume, Olympus Mons is 100 times larger than Earth's largest volcano, Hawaii's Mauna Loa. Scientists speculate that volcanoes on Mars can grow to such immense sizes because gravity there is much weaker than it is on Earth. In addition, while Earth's crust constantly moves, the Martian crust likely doesn't, although the debate among researchers continues. The Hawaiian islands were formed as a hotspot in the mantle created a chain of volcanoes in the crust cruising by above it, so if the surface of Mars isn't moving, a volcano could build up for longer in one spot.

"WHILE ORGANIC MOLECULES ARE COMMON ON EARTH, THEY CAN BE FOUND IN MANY OTHER PLACES TOO"

©Getty

10

THE GREAT RED SPOT IS SHRINKING

Along with being the Solar System's largest planet, Jupiter also hosts the Solar System's largest storm. Known as the Great Red Spot, it's been observed in telescopes since the 1600s and studied by modern instruments like those on NASA's Juno, which recently provided evidence that the storm is hundreds of miles tall and likely fed by winds from thousands of miles below. The storm has been a raging conundrum for centuries, but in recent decades another mystery emerged: the spot is getting smaller. In 2014 the storm was only 16,500 kilometres (10,250 miles) across, about half its historic size. The shrinkage is being monitored in professional telescopes, and also by amateurs. Amateurs are often able to make more consistent measurements of Jupiter because viewing time on larger, professional telescopes is limited and often split between different objects.

11

JUPITER'S MOON IO HAS HUGE VOLCANIC ERUPTIONS

Compared to Earth's peaceful Moon, Jupiter's moon Io may come as a surprise. The Jovian moon has hundreds of volcanoes and is considered the most active moon in the Solar System, sending plumes of sulphur up to 300 kilometres (190 miles) into its atmosphere. As such, Io's volcanoes emit around one tonne of gases and particles into space near Jupiter each second. Io's eruptive nature is caused by the immense forces the moon is exposed to nestled in Jupiter's gravitational well, as well as its magnetic field. The moon's insides tense up and relax as it orbits closer to and farther from the planet, generating enough energy for volcanic activity. Scientists are still trying to figure out how heat spreads through Io's interior, though, making it difficult to predict where the volcanoes exist using scientific models alone.



©NASA



"THE STORM HAS BEEN A RAGING CONUNDRUM FOR CENTURIES, BUT IN RECENT DECADES ANOTHER MYSTERY EMERGED: IT'S GETTING SMALLER"

12 THERE IS WATER EVERYWHERE

Water was once considered rare in space. But water ice exists all over the Solar System. It's a common component of comets and asteroids. Water can be found as ice in permanently shadowed craters on Mercury and the Moon, though we don't know if there's enough to support prospective human colonies in those places. Mars also has ice at its poles, in frost and likely below the surface dust. Even smaller bodies in the Solar System have ice: Saturn's moon Enceladus and the dwarf planet Ceres, among others.

Scientists suspect Jupiter's moon Europa may be the most likely candidate for extraterrestrial life because against all expectations there's likely liquid water below its cracked and frozen surface. Europa, much smaller than Earth, may host a deep ocean that researchers suggest could contain twice as much water as all of Earth's oceans combined.

But we know that not all ice is the same. A close-up examination of Comet 67P by the European Space Agency's Rosetta spacecraft revealed a different kind of water ice than the kind found on Earth.

© Tobias Roetsch



13 SATURN HAS A YIN-YANG MOON

Iapetus has a very dark hemisphere that always faces away from the planet and a very light hemisphere that always faces towards Saturn. Most asteroids, moons and planets are relatively uniform across their surfaces, but Iapetus sometimes shines brightly enough to be spotted by telescopes and then dims down by several magnitudes when oriented in the other direction. Current research suggests that Iapetus is made mostly of water ice. As the moon's darker side faces the Sun, scientists hypothesise, water ice sublimates away from that area, leaving darker rock behind. That may have created a positive feedback loop, as dark material heats up more than bright, reflective ice - as the darker, warmer side of the moon loses its ice, it becomes easier to heat up each time it faces the Sun, hastening the loss of more ice.

14 TITAN HAS A LIQUID CYCLE

Another weird moon in Saturn's system is Titan, which hosts a liquid 'cycle' that moves material between the atmosphere and the surface. That sounds a lot like Earth's water cycle, but Titan's immense lakes are filled with liquid methane and ethane, possibly over a layer of water. Researchers hope to use data from the Cassini-Huygens mission to tease out some of Titan's secrets before designing a submarine that might one day plumb the depths of the mysterious moon.

15 SATURN HAS A HEXAGONAL STORM

Saturn's northern hemisphere features a raging six-sided storm nicknamed 'the hexagon'. This hexagon, a towering, multilayered storm, has been present on the ringed planet for decades, if not hundreds of years. The strange storm was discovered in the 1980s, but was barely visible until the Cassini mission flew by between 2004 and 2017. Images and data from Cassini reveal the storm to be 300 kilometres (180 miles) tall, 32,000 kilometres (20,000 miles) wide and composed of air moving at about 320 kilometres (200 miles) per hour.

16 RINGS ARE MORE COMMON THAN WE THOUGHT

We've known about Saturn's rings since telescopes were invented in the 1600s, but it took spacecraft and more powerful telescopes built in the last 50 years to reveal more. We now know that every planet in the outer Solar System - Jupiter, Saturn, Uranus and Neptune - has a ring system. But the rings differ from planet to planet: Saturn's spectacular halo, made in part of sparkly, reflective water ice, is not repeated anywhere else. Instead the rings of the other giants are likely made of rocky particles and dust. Rings aren't limited to planets, either. In 2014 astronomers discovered rings around the asteroid 10199 Chariklo.

17

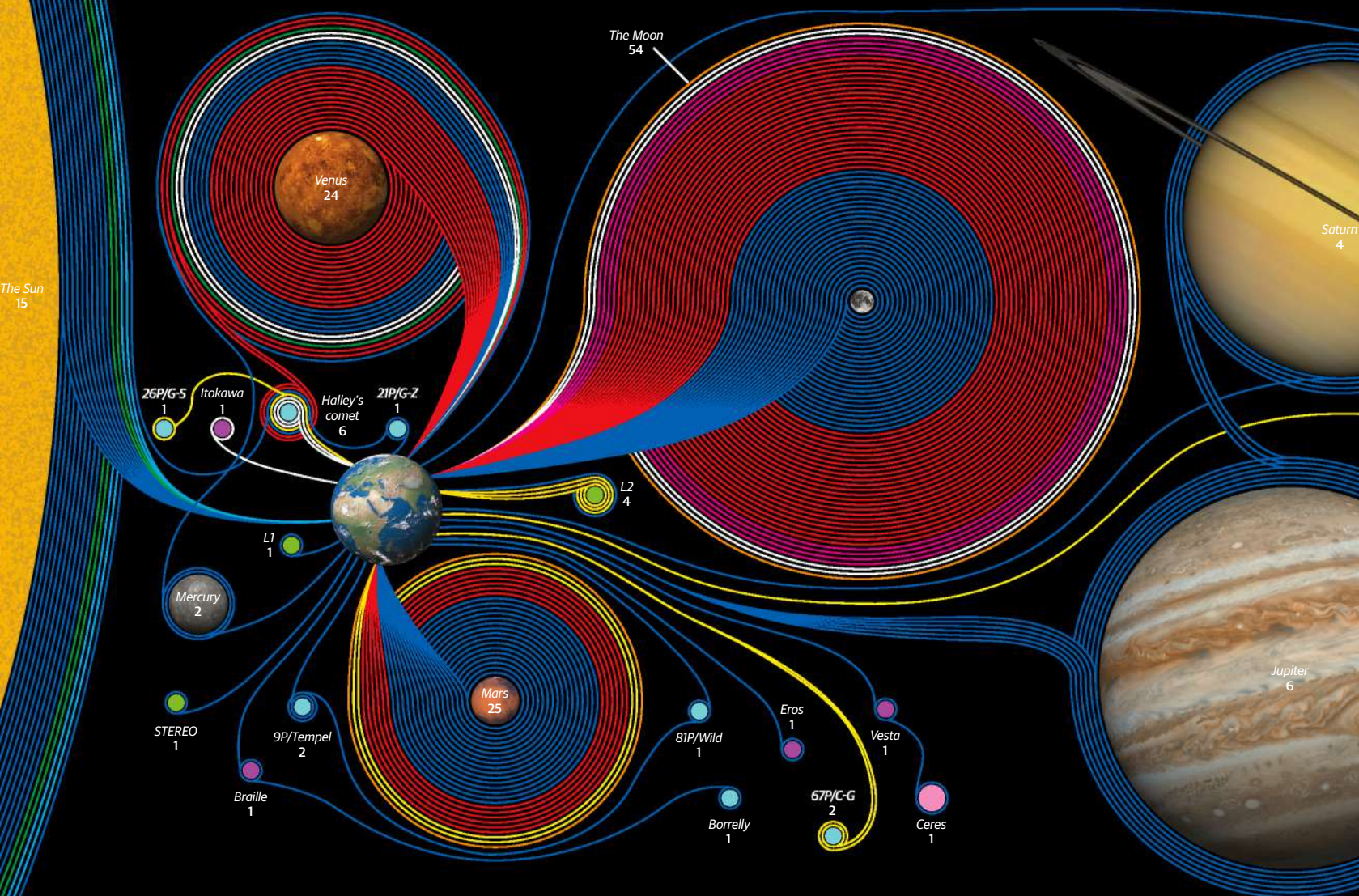
SPACECRAFT HAVE VISITED EVERY PLANET

We've been exploring space for more than 60 years, and have been lucky enough to get close-up pictures of dozens of celestial objects. Most notably, we've sent spacecraft to all of the planets in our Solar System - Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune - as well as two dwarf planets, Pluto and Ceres. The bulk of the flybys came from NASA's Voyager 1 and Voyager 2, which left Earth more than four decades ago and are still transmitting data from interstellar space. Between them the Voyagers clocked visits to Jupiter, Saturn, Uranus and Neptune thanks to an opportune alignment of the outer planets.

18 WORLDS COULD BE CONTAMINATED BY SPACECRAFT

So far, scientists have found no evidence that life exists elsewhere in the Solar System. But as we learn more about how 'extreme' microbes live in underwater volcanic vents or frozen environments, more possibilities open up for where they could live on other planets.

Microbial life is now considered likely enough on Mars that scientists take special precautions to sterilise spacecraft headed to the planet. NASA chose to crash its Galileo spacecraft into Jupiter rather than risk it contaminating the potentially habitable oceans of Europa.



19

MOST COMETS ARE SPOTTED WITH A SUNGRAZING TELESCOPE

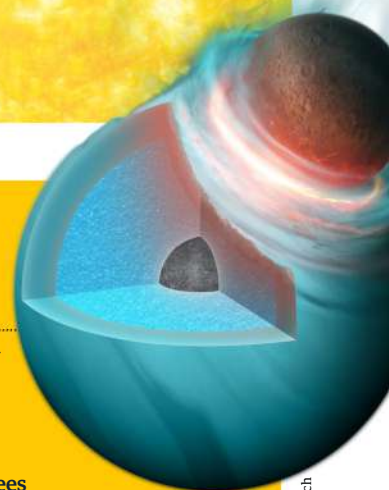
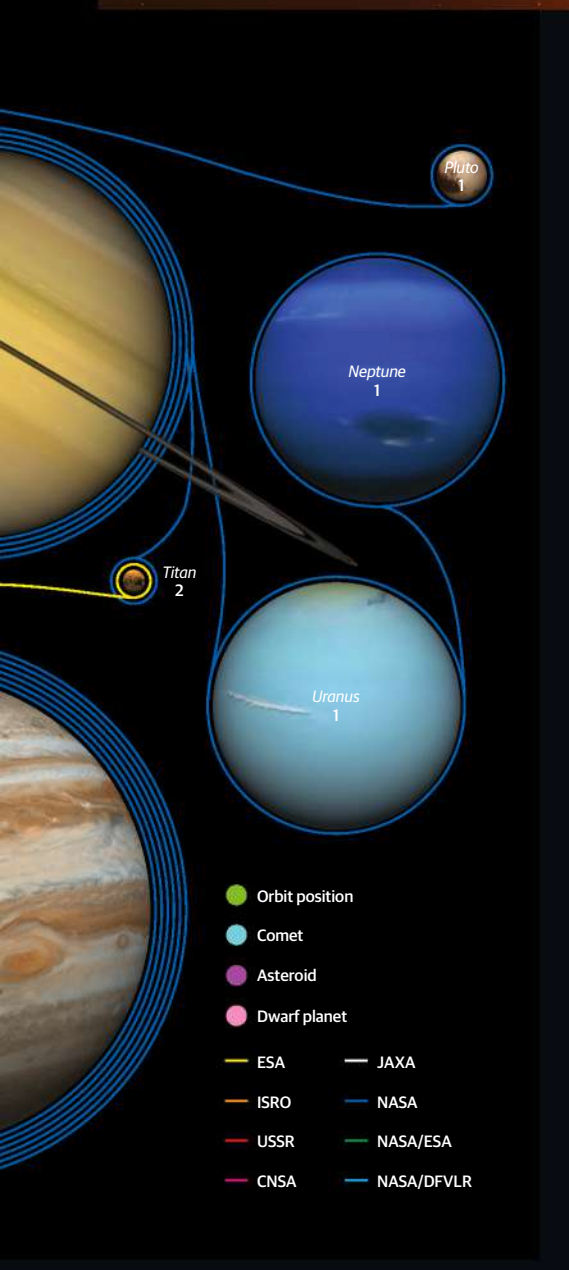
Comets used to be the province of amateur astronomers who spent night after night scouring the skies with telescopes. While some professional observatories also made discoveries while viewing comets, that began to change with the launch of the Solar and Heliospheric Observatory (SOHO) in 1995. Since then, the spacecraft has found more than 2,400 comets, which is a pretty productive side mission for a telescope meant to observe the Sun. These comets are nicknamed 'sungrazers'. Many amateurs still participate in the search for comets by picking them out from raw SOHO images. One of SOHO's most famous observations came when it watched the breakup of the bright Comet ISON in 2013.

20 URANUS SPINS SIDeways

This gas giant of the outer Solar System is pretty weird on closer inspection. First, the planet rotates on its side, appearing to roll around the Sun like a ball. The most likely explanation for the planet's unusual orientation - about 90 degrees sideways compared to the other planets - is that it underwent some sort of titanic collision in the ancient past. Uranus' tilt causes what NASA considers to be the most extreme seasons in the Solar System. For about a quarter of each Uranus year - or 21 Earth years, as each Uranus year is 84 years long - the Sun shines directly over the north or south pole of the planet. That means for more than two decades on Earth, half of Uranus never sees the Sun at all.

21 WHAT HAPPENED TO MIRANDA?

One of the most bizarre moons in the outer Solar System is Miranda, a shadowy moon of Uranus observed only once when Voyager 2 got a glimpse in 1986. Miranda hosts sharp ridges, craters and other major disruptions on its surface that would usually be the result of volcanic action. Tectonic activity could cause that kind of surface, but Miranda is much too small to generate that kind of heat on its own. Researchers think that gravitational pull from Uranus could have generated the push-pull action needed to heat, churn and contort Miranda's surface. To know for sure, we'll need to send another spacecraft to check out the moon's unobserved northern hemisphere.



22 NEPTUNE IS TOO HOT

Neptune is roughly 30 times as far from the Sun as Earth, and it gets correspondingly less heat and light. But it radiates far more heat than it's taking in and has far more activity in its atmosphere than planetary scientists would suspect, especially compared to nearby Uranus. Uranus is closer to the Sun and yet radiates about the same amount of heat as Neptune, and scientists aren't sure why. Winds on Neptune can blow up to 2,400 kilometres (1,500 miles) per hour. Is all that energy coming from the Sun, from the planet's core or from gravitational contraction? Researchers are working to find out.

23 THERE ARE MOUNTAINS ON PLUTO

A tiny world at the edge of the Solar System, scientists assumed the dwarf planet would have a fairly uniform, crater-pocked environment. That changed when New Horizons flew by in 2015, sending back pictures that altered our view of Pluto forever. Among the astounding discoveries were icy mountains that are 3,300 metres (11,000 feet) high, indicating that Pluto must have been geologically active as little as 100 million years ago. Geological activity requires energy, and the source of that energy inside Pluto is a mystery. The Sun is too far away from Pluto to generate enough heat for geological activity and there are no large planets nearby that could have caused such disruption with gravity.

24 PLUTO ALSO HAS A BIZARRE ATMOSPHERE

Pluto's observed atmosphere broke all the predictions. As data from NASA's New Horizons flowed in, scientists analysed the haze and discovered some surprises. They found about 20 layers in Pluto's atmosphere that are both cooler and more compact than expected. This affects calculations for how quickly Pluto loses its nitrogen-rich atmosphere to space. The New Horizons team found that tonnes of nitrogen gas escapes the dwarf planet by the hour, but somehow Pluto can constantly resupply that lost nitrogen. The dwarf planet is likely creating more of it through geological activity.

25

THERE MAY BE A HUGE PLANET AT THE SOLAR SYSTEM'S EDGE

In January 2015, California Institute of Technology astronomers Konstantin Batygin and Mike Brown announced - based on mathematical calculations and simulations - that there could be a giant planet lurking far beyond Neptune. Several teams are now on the search for the theoretical 'Planet Nine', and research suggests it could be located within the decade. This large object, if it exists, could help explain the movements of some objects in the Kuiper Belt, an icy collection of objects beyond Neptune's orbit. Brown has already discovered several large objects in that area that in some cases rivalled or exceeded the size of Pluto, but scientists are pursuing another theory, too - that Planet Nine could in fact be a grapefruit-sized black hole, warping space similarly to the way a gigantic planet would. Yet another team suggests that the weird movements of the far-flung Kuiper Belt occupants could be the collective influence of several small objects, not an undiscovered planet or black hole at all.

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IN-FLIGHT EXPLORATION

To explore another planet faster than a rover and in more detail than a satellite, we need to fly, and the best way to do it may be to copy birds

When we first started to build flying machines, we began by copying birds. In the initial stages of human flight, numerous people tried jumping from high places with poorly designed wings, leading them to fall to their deaths - the earliest account of this is of a man named Armen Firman trying it out during the 9th century. Despite this, attempts at flapping-wing flight continued into the machine age. It wasn't until 2010 that a team from the University of Toronto, Canada, made the first successful flight of a piloted, engine-powered ornithopter - a craft that 'flaps' its wings.

While fixed wings combined with a separate source of propulsion finally took us into the air, flapping-wing flight has a lot of potential benefits - it's just really hard to do. But now, if a study presented to the NASA Institute of Advanced Studies comes to fruition, then remarkable, solid-state, solar-powered ornithopters could be flying on other planets sooner than we think.

The Solid State Aircraft (SSA) study has been led by Anthony Colozza of the Ohio Aerospace Institute, with contributors from universities across the US. With their unique aircraft concept, engineers are looking to combine thin film solar cells and thin film batteries with an electrically responsive synthetic muscle material to create an aeroplane with no moving parts.

Designed as a rectangular flying wing with no tail, solar energy would be collected by flexible photovoltaic cells at just a thousandth of a millimetre thick. Despite their thinness, they can convert ten per cent of the light falling on them into electricity while still being able to flex with the wing. This energy would then be stored in thin film lithium-ion batteries, which are of a similar chemistry to the batteries used in smartphones and computers. However, they are produced by spraying the layers that make up the battery, such as the electrical contacts

and the electrolyte - the substance that allows the charge to flow - in thin layers onto a flexible backing. This backing could then be used as the back of the solar cells.

The power supply could be used to drive the ionic polymer-metal composite (IPMC) - this is material that acts like a muscle, flexing when electricity is applied. It's made of a substance called ion-exchange membrane, which is coated with metal layers. When electricity is applied to the metal layers, it causes molecules of water and sodium in the membrane to cluster at the negative terminal. This makes the negative side expand and the positive side contract, bending the membrane and flexing the wing. The IPMC could be incorporated as skeleton-like strips into the wing, or indeed spread out over the whole wing, with the pattern of the electrodes determining how it flexes. Given the combination of power supply, storage and propulsion into these thin films and the availability of miniature computing and sensors, the SSA could be an intelligent flying plastic sheet.

The SSA's incredible simplicity and low mass would be great advantages for missions exploring other planets, where every kilogram costs millions of pounds to deliver and there's no chance of making repairs. Flapping is the most efficient form of flight, with the SSA making it possible to cruise around Venus indefinitely or grasp a hold in Mars' tenuous atmosphere.

1 FLAPPING WINGS

The IPMC material acts like the muscles of a bird, working to flap the wings. This is a very efficient form of flight, providing lift, control and propulsion from a single structure.

2 COLLAPSE TO FIT

As it's made of thin, flexible films, the SSA can be folded up into a very small volume, making it easy to pack into a mission. Several models could be rolled up together.

3 FLYING FORM

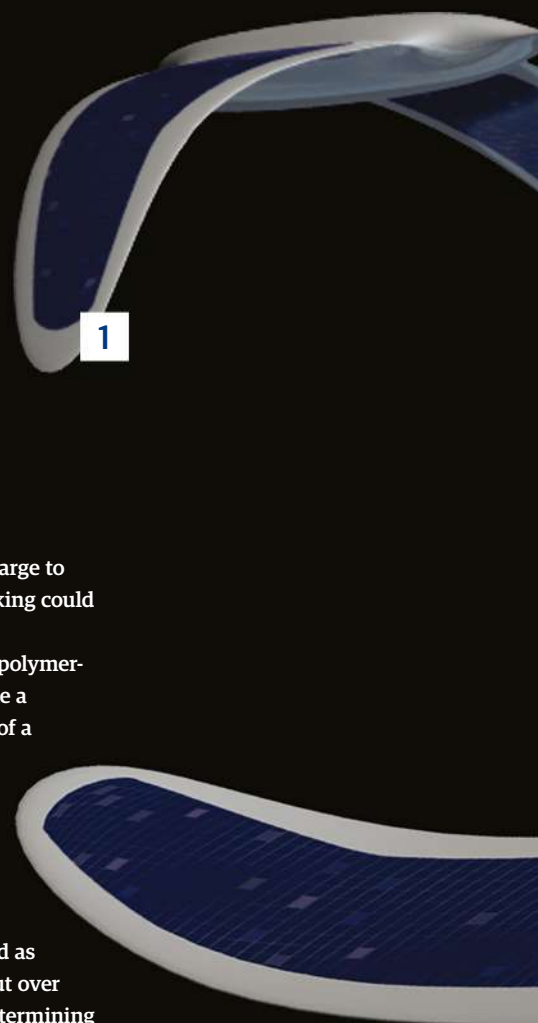
The SSA is able to flex its wings like a bird. This provides all flight control without the need for a separate tail or flaps.

4 PAYLOAD

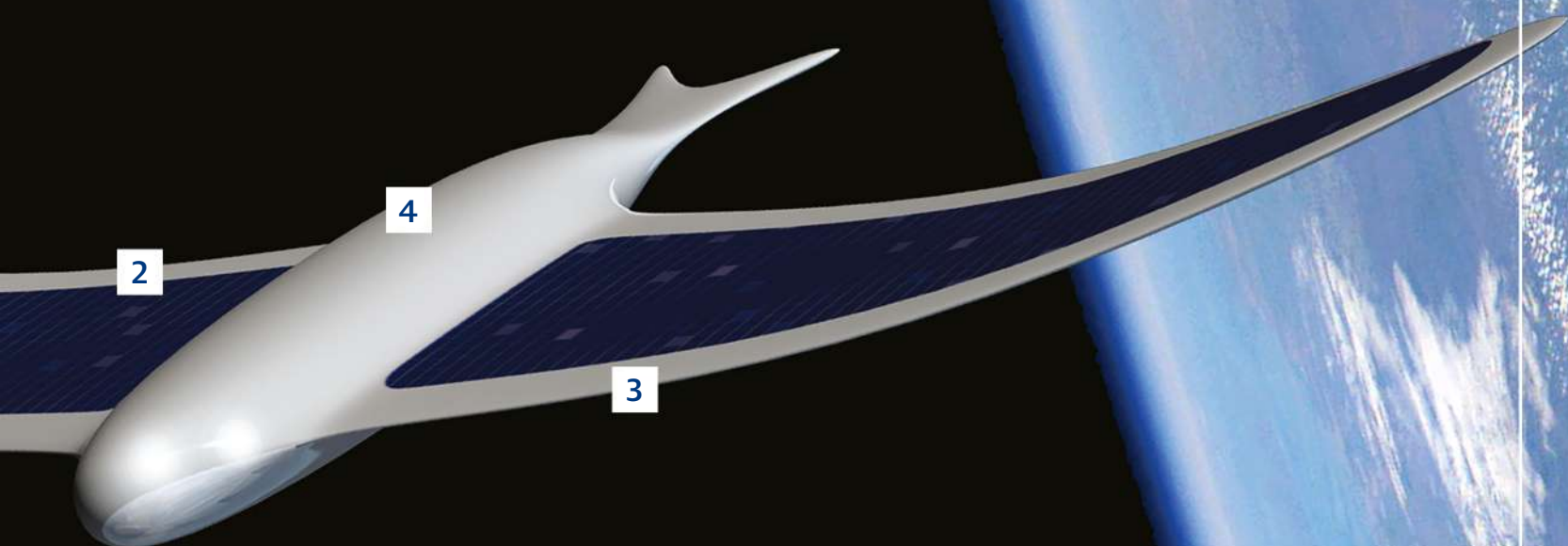
Such an aircraft could carry a range of environmental sensors for exploring another planet, profiling the atmosphere at different altitudes or photographing the surface in great detail.

5 PLANETARY ATMOSPHERES

The rocky planets all have their own challenges. Venus has good solar power and a dense atmosphere, but corrosive clouds, while Mars has low gravity and a thin, cold atmosphere of low density.



"FLAPPING-WING FLIGHT
HAS A LOT OF POTENTIAL
BENEFITS – IT'S JUST REALLY
HARD TO DO"



6 SOLAR CELLS

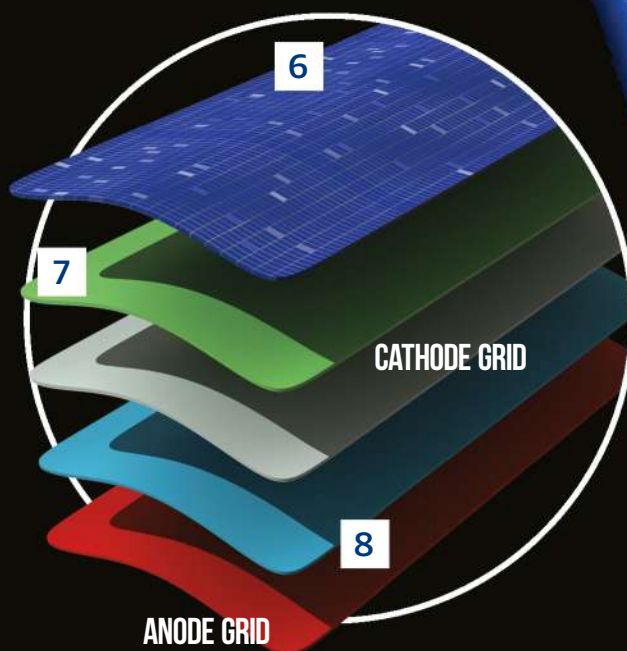
Solar cells created on a thin, flexible plastic will cover the entire surface of the SSA, converting light into electricity to power the aircraft.

7 THIN FILM BATTERIES

Produced by spraying thin layers of battery materials onto a flexible backing, these will store the electricity created by the solar cells.

8 IPMC

This material is an organic membrane coated with metal on both sides. When charge is applied across the surface, it flexes towards the negative terminal, working like a muscle.



INTERVIEW

“

BIO

Eileen Collins

Born on 19 November 1956, Eileen Marie Collins served as a pilot in the United States Air Force before becoming one of the most decorated astronauts in NASA history after her selection in 1990. She served on four separate Space Shuttle missions, including the first American rendezvous with Russia's Mir space station and the return-to-flight mission after the Columbia accident. After completing over 872 hours in space, she retired from NASA on 1 May 2006 to pursue private interests, but retains an interest in space exploration to this day.





EILEEN COLLINS

“IT WAS A DIFFICULT MISSION... WE WERE THE FIRST TO SEE MIR”

Having served as both the first female pilot and first female commander of NASA's Space Shuttle, Eileen Collins boosted the involvement of women in space exploration to a whole new level

Interviewed by Jonathan O'Callaghan

How did you become interested in space exploration?

It all started when I was nine years old; I was in fourth grade reading an article in a magazine about the Gemini program. They were profiling the astronauts and the missions, and that was when I really, as far back as I remember, found myself very interested in the space program. While I attended summer camp as a child I would visit the glider field and we'd watch the gliders take off. So there was a little bit of aviation in my background, and I think that's maybe the roots of my getting interested in aviation and space.

Were you proud to be selected as the first female Space Shuttle pilot?

Back in 1989 I interviewed for the job of Space Shuttle pilot, and in January of 1990 I talked to John Young and he told me that I was selected, and also I was going to be the first woman pilot. It was 16 January 1990; I remember the date. I went through training from the summer of 1990 to the summer of 1991. It was September of 1993 when

I was actually assigned to a flight, and then that mission [STS-63] didn't fly until February of 1995.

Then, of course, there was a lot of attention. Was it a proud moment? I would say yes, but not for me as much as it was, I think, for the space program and for women in general. Even though women had flown in space as mission specialists, no women had flown yet as a pilot. I think it was a good step for women in general overall, and I've actually had women that worked in the Kennedy Space Center say to me that now that I've done what I've done they are getting more respect from their male coworkers.

Did other female astronauts inspire you?

Oh yes, definitely. Sally Ride, she was a role model for me - she flew in 1983 and again the next year. And Valentina Tereshkova, who I met in 1995, she was the first woman in space, and then Svetlana Savitskaya was the first woman to do a spacewalk. The third Russian woman was Yelena Kondakova. But the Russians have only flown three women in space, while the Americans have flown over 40.

So Russia needs to start getting some women in their program. I'm really surprised that they are not doing that.

Has there been a shift to a more inclusive astronaut program in America?

Yes, inclusive in the sense of what you look like isn't important. It's kind of silly for me to say this because it's so well accepted and part of our culture now, but what you look like, man or woman, colour of your skin or other factors about you are not as important as your ability to contribute to space exploration. So your experience, your college degree, your motivation to help with space exploration, that is by far more important than all these other things like are you a man or a woman. From the mission side it's all about getting the right people to make the mission safe and successful.

Could the first person on Mars be a woman?

That's going to be a difficult decision, who is going to be the first person to step on Mars, because

INTERVIEW



THE FUTURE IS VERY EXCITING — WE JUST DON'T KNOW WHAT'S GOING TO HAPPEN

you saw what happened to Neil Armstrong. He became a huge celebrity because he was the one who put his foot down there first, and even though Buzz Aldrin was with him, Buzz went second. To me I don't know if it makes that much difference which one steps down first, but Neil was the commander, so he went first. Somewhere along the line we have to pick who will be the first one to step on Mars.

My question is will it be an American, because whether it's a man or a woman, I don't know if that's important to me. I mean, I would like to see a woman, I think it'd be wonderful to see a woman as the first person to walk on Mars, but I think it's more important that the United States makes a commitment to be the first country there, because otherwise we're going to lose our leadership.

I still believe that China certainly has the ability to be the first country on Mars, and I think there are even some other countries out there that could be first that are showing interest in a strong space program. The US has some good ideas, but I think we need a better commitment in our budget. The other question is will it be a country or a private company, because it could also very well be a private company that sends their people first. Who knows. The future is very exciting – we just don't know what's going to happen.

Is the commercialisation of space a good thing?

Yes. In fact, having private industry go to low-Earth orbit is going to save us, because our country does not have the budget to continue to service the space station in low-Earth orbit and do deep-space exploration. I think that's definitely the way to go – have private industry service the space station with people and cargo and use NASA's budget to do the things that maybe the private industry isn't willing to do right yet.

Do you think NASA's goal of exploring deep space with the Orion spacecraft and SLS is a good one?

Yes, I do. I really do. I think that it's a little more traditional, but I think that it is the right goal. Deep space is an important thing for us to do, to continue to explore and get people off the planet and find out what's out there.

What was that first mission like, STS-63?

It was a difficult mission because we were the first Americans to see the Mir space station in 1995. We were doing something for the first time, a rendezvous, but we didn't dock. We just did the rendezvous and the close approach. The whole thing was to test out the Shuttle's flying ability, the rendezvous trajectory, our navigation aids and the communications systems.

We were the test flight for the couple of flights after us that did the first docking. Because it was such a test flight, and so many of the things were done for the first time, it was a difficult mission to develop. Plus we had to do a lot of negotiating with the Russians. The main question from the crew's point of view was how close were we going to go.

We were going to go to 1,000 feet [3,280 metres] from Mir, then we negotiated to 100 feet [328 metres], and in the end we negotiated to 30 feet [98 metres]. The actual rendezvous itself went to 37 feet [121 metres]. And that was not easy, getting everyone to agree it was safe to go that close. But frankly we made the docking missions a lot safer with less unknowns by us flying closer. That was the biggest challenge, coordinating to get that close, and then of course one of the most exciting things about the mission was for us to be able to look out the window and wave at the cosmonauts and take pictures. It was just kind of fun.

Was it a surreal moment being that close to Mir for the first time?

It was, but I'm going to tell you, I was very nervous during the whole thing because you never know when you do something for the first time what's going to break, if you're going to have an unexpected emergency or malfunction. So I was a little bit nervous about the whole thing, and

rightfully so. But once we did the close approach and we were in there at 37 feet [121 metres], we waved at them, and it just really felt like we had accomplished so much. And then my commander Jim Wetherbee made this radio call that I'll never forget – it was something like “as we bring our spaceships together, we are bringing our nations together”. He said that while he was flying just 37 feet [121 metres] away from Mir. That was one of my biggest memories.

What were some of the highlights from your other three missions?

On my second mission [STS-84, May 1997] we docked with Mir, and I think the highlight was just being on the Mir space station, which was very old at that point in time. But it was very comfortable, very liveable and I enjoyed being there. My third mission [STS-93, July 1999], the highlight without a doubt was the successful deployment of the Chandra X-ray Observatory.

Between NASA and TRW [the aerospace company that built Chandra], it was a fantastic observatory, and I'm so proud to say that my crew was able to take it up safely and deploy it. It was built for a five-year mission and it's up there extended for over 22 years now.

My fourth mission [STS-114, July 2005] was getting the Space Shuttle flying again after the Columbia accident [on 1 February 2003]. Sometimes I look back and I can hardly believe I did all that. Was I part of the teams that made those amazing missions happen? It's hard to believe I was, and here I am today retired looking back at it.

Were you nervous on that return-to-flight mission after the Columbia accident?

Of all the flights I think the one that concerned me the most was the first one doing that Mir rendezvous. That might have just been the fact that it was my first flight in space, and there were a lot of unknowns with it being my first flight.

For my last mission I was tremendously confident. I was the commander, I had flown three times before and I really knew what I was doing. Of course you always have an unknown, but I think experience really gives you a strong feeling of confidence, which I think is very important. If you're the leader as commander, you're not only the leader of your crew on the mission but you're setting the tone for all the people working in the program around the planet. So I was truly very confident and ready to fly that mission. I wasn't going to accept the mission and fly it until I was convinced that we were going to have a safe and successful flight.

Now, there were some unknowns. We did repair tests in space for the first time and we did an inspection of the exterior of the Shuttle heatshield for the first time. There were a lot of firsts on that

mission, but I was very confident in my crew. I knew them very well and they were all very smart and dedicated, so I think my last mission was probably the one I had the most confidence in.

Were you sad to see the Shuttle retired?

Yes, very much so. I was very sad to see it retired. I still believe the Shuttle could have flown longer than it did, but it was not promoting a change in the policy. I think it was around 2008 that I was on the NASA Advisory Council and the Shuttle program manager said: “If you want to change your mind about retiring the Shuttle you need to tell me right now because I am closing out contracts, the pipeline for supplies is shutting down, certain supplies just aren't being made any more and the decision is being made where we're at the point of no return.”

The longer we waited to change our mind on Shuttle retirement, the more expensive it was going to be to start that program back up again. And when we got to 2010 and people started saying, Constellation is cancelled, Ares 1 is cancelled, now we have no way to get to the space station, let's keep the Shuttle flying. Well yeah, maybe that would have been the right thing to do, but it was extremely expensive at that point to try and get the Shuttle flying again. Basically the right decision at that point was to keep shutting down the Shuttle program. By the time we got to 2010 it was just too expensive and just extremely ineffective to change our minds. So I agreed with

the decision to shut down the Shuttle, as sad as it was, and I'm sorry that it had to happen the way it did.

Are there exciting times ahead, though?

Yeah. I think the Orion spacecraft and the Space Launch System are going to fly. It's going to be expensive, but space programs cost money. Should we do it? Yes, without a doubt, we definitely need to do it. I don't want to see it stretched out and delayed any more. If you stretch it out it just gets more expensive. So yes, they should fly. They should stay on schedule. They will have some problems, but that's what you expect from a new program. When we have problems we shouldn't just cancel the program; we need to fix the problems and keep going. I don't like the idea of giving up on something because it's not as perfect as we thought it was going to be. I mean nothing's perfect. You just need to stick with it, make it right, make it safe and get it flying.

Are you still involved in space?

Yes, very much so. I read space news every day. I stay up to speed with what's happening and I'm joined a board that works for the National Academies called the Aeronautics and Space Engineering Board. When you jump to a new career field you've got a great big learning curve, and it takes a lot of time, but I enjoy human spaceflight so I try to stay mostly involved in that area.

Top Left: The STS-114 crew before their mission

Right: Collins feeling the effects of microgravity in space



©NASA



VIRGIN ORBIT TARGETS SUMMER FOR ITS FIRST ORBITAL LAUNCH

The California-based company has three straight successful orbital missions under its belt

Reported by Elizabeth Howell



"THIS IS THE START OF A GREAT COLLABORATION,
AND WE'RE SO EXCITED TO SEE WHERE IT GOES"

JOSHUA WESTERN



Fresh on the heels of a third straight successful launch from California earlier this year, Virgin Orbit plans to extend its liftoffs to the United Kingdom. The company aims to launch for the first time this summer from Spaceport Cornwall in the western UK. The mission will loft a satellite for Space Forge, an in-space manufacturing startup based in Wales. The coming flight will be the first orbital mission ever to launch from the UK and the first to carry a satellite developed in Wales.

"We're thrilled to be making UK history with our first launch," said Space Forge CEO Joshua Western. Space Forge wants to test a new mini space manufacturing factory called ForgeStar, which will seek to return to Earth products made in space. "We will demonstrate the use of space for good through in-space manufacturing and reliable return, and it's brilliant that both Virgin Orbit and Spaceport Cornwall share our ambitions," Western said. "This is the start of a great collaboration, and we're so excited to see where it goes."

Virgin Orbit conducts its launches using a modified Boeing 747 called Cosmic Girl, which totes a rocket called LauncherOne beneath its wing to deploy satellites in space. Virgin Orbit

says the 21-metre (70-foot) LauncherOne, which can launch up to 500 kilograms per mission, has an advantage over traditional vertically launched rockets as air-launched missions are more responsive and flexible. Virgin Orbit is part of the same group as space tourism provider Virgin Galactic; both companies belong to billionaire Richard Branson's Virgin Group. Virgin Orbit's debut orbital test launch in May 2020 failed after a fuel line in the rocket's first stage burst. The company recovered to post three straight successful launches in 2021 and 2022.

In January, Virgin Orbit said it plans to launch five more missions in 2022, including two from Spaceport Cornwall. The other three will lift off from Mojave Air and Space Port, the takeoff point of all Virgin Orbit missions to date. "The Cornwall launches are targeted around the middle of the year - summertime," Virgin Orbit CEO Dan Hart said. "That's predicated on getting through the licensing process successfully and some of the logistics, but that is what we're driving for," he said. "And [this] will be the first launch ever from UK soil and the first [orbital] launch ever from the European area." Virgin Orbit is also seeking other locations to launch from. Early possibilities could include Guam, Japan and Brazil, with more long-range opportunities potentially in play in Australia and "several European countries, as well as countries in other areas," Hart added.

1 PAYLOAD MODULE

Once the second-stage thrusters are fired, the clamshell halves separate to release the satellite at the tip of the rocket. It's capable of placing 300 kilograms into a Sun-synchronous orbit or 500 kilograms into low-Earth orbit.

2 SECOND STAGE

The final, less powerful thruster will fire the second stage to orbit, with NewtonFour delivering 22 kilonewtons of thrust.

3 FIRST STAGE

Once reaching a 9,100-metre (30,000-foot) altitude, the NewtonThree rocket will fire its pump-fed liquid-fuel rocket engine. The NewtonThree engine produces 330 kilonewtons of thrust.

Hubble has taught us so much about the universe



© NASA

USER MANUAL

Hubble Space Telescope

With 30 years of service under its belt, the long-serving mission remains one of the greatest and most influential cosmic lenses

THE SPECS

Launch: 24 April 1990

Rocket: Space Shuttle

Discovery (STS-31)

Target: Low-Earth orbit

Operators: NASA

Estimated cost: \$1.5 billion

Time in space: 32 years

Orbit height: 547 kilometres
(340 miles)

Spinning high above our world in the embrace of a low-Earth orbit lies Hubble, an observatory that's served as the backbone of modern astronomy for over three decades. Its cameras have stared out into our Solar System and beyond, helping scientists, astronomers and academics to slowly peel back the mysteries that lie far beyond the blanket of our atmosphere.

The Hubble Space Telescope may be an ageing amalgamation of engineering from across the decades, but its impact on astronomy is truly unmatched. When it launched on 24 April 1990, Hubble represented the biggest step forward for the field since Galileo Galilei turned his homemade telescope to the stars in 1610. Humankind no longer had to rely on terrestrial observatories; it now had one high above the Earth with the power to peer far beyond our capabilities at the time.

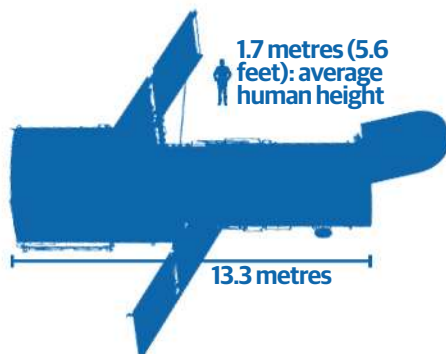
Hubble can trace its origins as far back as the 1920s, when German astronomer Hermann Oberth theorised that telescopes could be sent into space via rockets. Two decades later, American theoretical physicist Lyman Spitzer was championing that same idea. By 1969, following his proposal to Congress, NASA had turned its attention and resources to designing humankind's first true space telescope. It was an incredible

project - one that would eventually exceed \$1.5 billion (£1.14 billion) by its launch - yet it would be a rocky road to takeoff.

Hubble, named after the influential astronomer Edwin Hubble, was originally planned to launch into space in 1983, but after it slipped to a new deadline three years later the program found itself placed on standby following the Space Shuttle Challenger disaster that killed its crew of seven. The tragedy rocked NASA to its core, but Hubble would eventually lift off from American soil aboard the Space Shuttle Discovery as the 20th century rolled into its final decade.

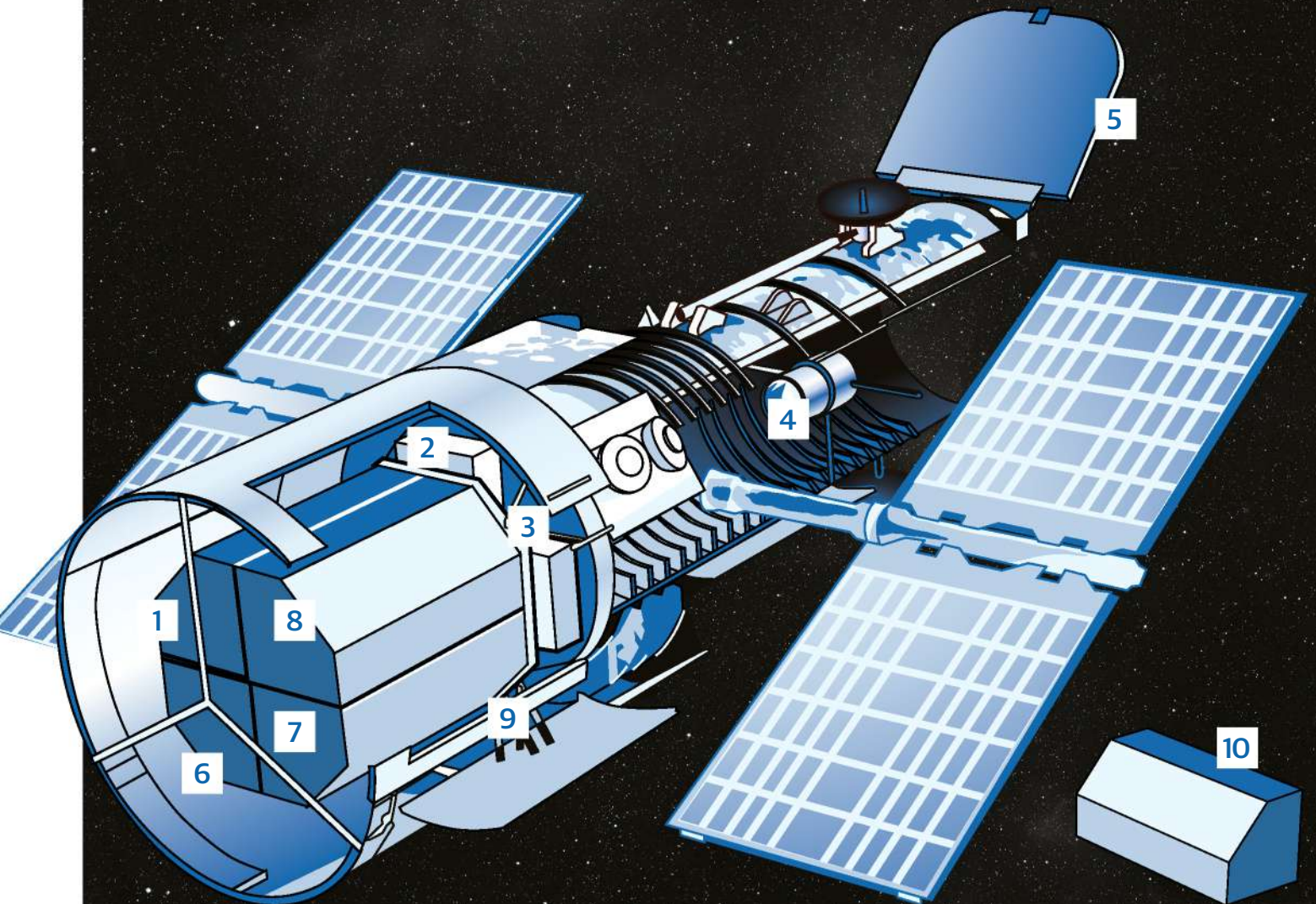
Hubble began its observations with five instruments to its name: the Wide Field and Planetary Camera (WFPC), the Goddard High Resolution Spectrograph (GHRS), the High Speed Photometer (HSP), the Faint Object Camera (FOC) and the Faint Object Spectrograph (FOS). Each instrument had contributions from NASA's entire breadth, ranging from the Jet Propulsion Laboratory to the Goddard Space Flight Center, and together they represented the most advanced technology the organisation could fit into one space-bound telescope.

But for all that funding and an incredible amount of workmanship and engineering, Hubble's



Anatomy of the Hubble Space Telescope

The spacecraft's instruments have stood the test of time as it gazes deep into our Solar System and beyond



1 Space Telescope Imaging Spectrograph

One of the most powerful instruments on board Hubble, STIS is used to cover a huge spectra of wavelengths, including ultraviolet and infrared.

6 Near Infrared Camera and Multi-Object Spectrometer

NICMOS is used for infrared astronomy. It detects light with wavelengths of 800 to 2,500 nanometres.

2 Fine Guidance Sensor

Hubble uses three fine guidance sensors - two of these are used to lock the telescope onto a target, while the third is used for astrometry.

7 Advanced Camera for Surveys

Like many instruments on Hubble, ACS was built, tested and installed long after Hubble's launch. It replaced the Faint Object Camera.

3 Primary mirror

Hubble's main mirror is perfect for reflecting ultraviolet light thanks to glass that's been coated with aluminium and a special compound.

8 Cosmic Origins Spectrograph

Designed to support STIS, COS is used to perform spectroscopy on faint-point sources.

4 Secondary mirror

The secondary mirror also has a special coating over its glass and is used to direct the light from the primary mirror to the instruments.

9 Wide Field Camera 3

WFC3 is Hubble's latest and most technologically advanced instrument, taking images in the visible spectrum.

5 Aperture door

The aperture door functions as a safety valve that closes every time there's a danger that light from the Sun, Earth or Moon could pass into its mirrors.

10 Faint Object Spectrograph

FOS was one of the original instruments used on Hubble. It was replaced with STIS in 1997.

SERVICING AN OBSERVATORY

1 Blasting off

In order to service Hubble, NASA launched a Space Shuttle via a pair of solid rocket boosters and an external tank. This contained all the replacement parts and a mechanical arm.

2 Heading for low-Earth orbit

The Space Shuttle, with a team of astronauts on board, broke away from its boosters as it powered towards a low-Earth orbit with the components to service Hubble.

3 Operating the arm

Controlled via Mission Control and monitored by the astronauts themselves, NASA used the Canadarm, or Shuttle Remote Manipulator System (SRMS), to begin removing faulty components.

4 Installing new components

Over the course of around nine days, degraded or faulty elements were replaced by new and upgraded instruments and tools, enabling Hubble to continue its mission.

5 Returning to operation

After 10 or 11 days, the Space Shuttle retracted the Canadarm and began its trip back to Earth. Hubble could now resume its stargazing vigil.

initial images were blurred and out of focus.

Its primary mirror was found to have minute undulations around its edge which caused the light to bounce off in a way ground control couldn't account for. It took over three years for NASA to remedy the problem, sending up the first service team to replace the telescope's main camera with a modified version. Suddenly Hubble could see clearly, and the results were astounding.

Over its decades of service, Hubble has dramatically changed how we see the wider universe. Through its instruments, astronomers have been able to accurately measure stars using Cepheid variables - stars that pulse radially. Since such measurements were virtually impossible from terrestrial telescopes, we're now able to determine the Hubble constant and understand just how fast the universe is expanding around us.

Thanks to its set of sensitive instruments and lenses, Hubble has also been able to shed more light on black holes and their relationships

with the galaxies they reside in. Prior to

Hubble, scientists theorised that

black holes were common

in some galaxies, but

data collected by the

space telescope has

revealed it's more

than likely most

galaxies have

black holes at

their centres

"HUBBLE HAS
CHANGED HOW WE
SEE THE WIDER
UNIVERSE"

and that these cosmological anomalies share a deep connection with their homes, like our own supermassive black hole Sagittarius A*.

Hubble has even discovered the farthest known galaxy to date, GN-z11, a high-redshift galaxy found in the constellation of Ursa Major. This far-off cosmic locale was observed in 2015 as it existed 13.4 billion years ago, which was around 400 million years after the Big Bang. The observation of GN-z11 is just one of countless discoveries Hubble has made, with over a million images already snapped since its cameras began operating optimally in 1993.

So what's next for Hubble? The observatory's orbit is slowly degrading, which is causing the telescope to drop in height over time. This has been corrected during the five service missions conducted by NASA, but it's clear Hubble's time in operation has a shelf life that's rapidly running out. Then there's the James Webb Space Telescope (JWST), which is still preparing itself out in orbit. Launched in December 2021 after being set back so many times, the JWST will serve as the observatory's spiritual successor.

NASA has yet to confirm how Hubble will eventually be decommissioned, but some of those involved in the program have suggested it could be brought out of operation via a controlled deorbit and guided down into the ocean. However Hubble will be retired, it's clear that its impact on the future of astronomy will survive long after the observatory's demise.

TOP TECH

Wide Field Camera 3: Hubble's advanced eye

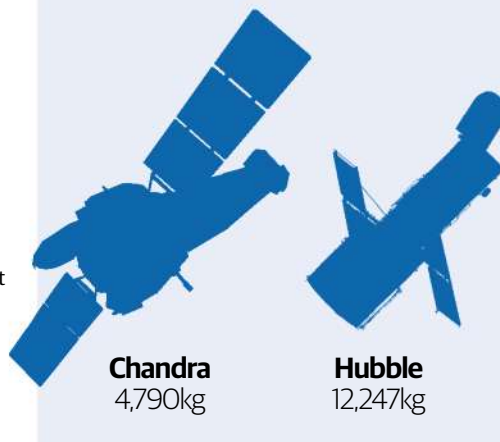
For years the most powerful lenses staring out into the cosmos were the Wide Field and Planetary Camera and Wide Field and Planetary Camera 2. As the years passed, one would replace the other, until 2009, when NASA installed one of the last instruments to be added to the observatory before it's replaced by the James Webb Space Telescope. The WFC3 is still impressive, utilising two independent light paths: an optical channel that takes images from 200 to 1,000 nanometres and a near-infrared detector array that covers the wavelength range from 850 to 1,700 nanometres.



© NASA

Head to head Hubble vs Chandra

When it comes to weight, Hubble remains one of the chunkiest craft at 12,247 kilograms - 1,361 kilograms more than its original launch weight and heavier than the Chandra X-Ray Observatory, which clocks in at 4,790 kilograms. In terms of sheer size, Hubble isn't quite as grand as the far newer Chandra, with its measurements coming in at 13.3 by 4.2 metres compared to Chandra's larger 13.8 by 19.5 metres. Hubble and Chandra both almost occupy the same space as a double-decker bus, with a length of 15 metres and height of 4.3 metres.



HOW TO...

Establish a space telescope

1 The big launch

Getting a large space telescope into space requires an incredibly powerful rocket to take it into low-Earth orbit. Since NASA was in the middle of its Space Shuttle Program in 1990, Hubble was launched inside Discovery.



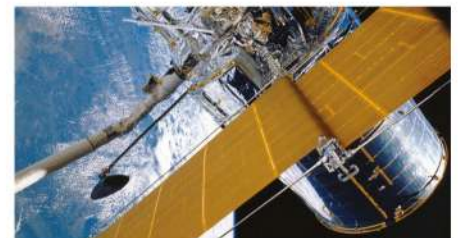
2 Reaching low-Earth orbit

To get Hubble into place, Discovery soared to a height of 600 kilometres (373 miles) above Earth, separating itself from the three boosters. At this height, Discovery's crew of five was able to document the operation.



3 Unfurling the solar array

As the Hubble Space Telescope was removed from Discovery's cargo bay, the remotely operated Canadarm robotic arm was unfurled. However, one of Hubble's solar arrays refused to fully unfurl, so an emergency spacewalk was prepped.



4 Launching Hubble into place

Following five days of operation - which included a number of experiments - the Hubble Space Telescope was tested and separated from Discovery. As it began its long vigil above Earth, Discovery and its crew returned home.



© NASA/ESA/Hubble

Vital statistics

13.3 METRES = The length of Hubble

4 BILLION MILES = The distance Hubble has orbited since 1990

844GB = The amount of data that Hubble captures every month

17,500MPH = The speed of Hubble's orbit around Earth

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PLANET PROFILE

VENUS

Earth's sister planet is a harsh, deadly world, making it an interesting one to observe

Hell on Earth is a phrase used by many, but one planet actually matches this idea of a harsh and inhospitable environment - that accolade falls to Venus. The second planet from the Sun is similar in size and density to Earth, with it being only 638 kilometres (396 miles) smaller in diameter and 0.27 grams per cubic centimetre lower in density. These physical dimensions may paint a picture of a world similar to Earth, but that's far from the case. Venus underwent a different evolution, and its dense atmosphere has fashioned the hottest surface temperature in the entire Solar System at 465 degrees Celsius (869 degrees Fahrenheit), with atmospheric pressures that are over 90 times that of Earth's at sea level.

Venus' atmosphere is composed mainly of the greenhouse gas carbon dioxide, with small amounts of nitrogen and traces of other gases, most notably sulphur dioxide and argon. Comparing this atmosphere to Mars' - which is about 100 times thinner than Earth's - again highlights that these planetary evolutions took opposite approaches; one planet lost its atmospheric greenhouse gases while the other formed a thick atmosphere and as a result traps heat in a runaway greenhouse effect.

In between these planets - both literally and scientifically - is Earth. It has moderate amounts of greenhouse gases that allow it to trap enough heat to maintain a habitable surface

temperature that's perfect for the existence of life. Looking at the surface of Venus has revealed some extremely interesting characteristics that help astronomers and planetary scientists understand the planet's true interior. For instance, volcanoes have been observed on Venus, such as Idunn Mons in the planet's southern hemisphere, rising 2.5 kilometres (1.6 miles) above the surrounding plains. This volcanism is a sign that there is active mantle underneath the rocky surface. This would explain what is powering these volcanoes and also what is replenishing the sulphur dioxide in the atmosphere, creating the acidic clouds. It's also been theorised that Earthlike thunderstorms occur and sulphuric acid rain peppers Venus' surface, originating from the acidic clouds. Although volcanoes indicate that the planet's surface can be smoothed over by running lava, making it appear younger, there have still been many impact craters spotted on the surface.

Scientists have theoretically scratched the surface, revealing that the interior of Venus is likely composed of a partially liquid metallic core and a rocky mantle above that. This theory is based on the calculated mass and density of the planet, suggesting it's made up mainly of rocks and metals. This remains a theory for now due to observations being much harder because of the planet's thick atmosphere.

Venus hasn't had the same degree of surface visits and orbiter attention as Earth's neighbour on the other side, Mars, due to its lead-melting surface temperature and toxic acid clouds, but it has still been visited by several spacecraft. It has also been influential in providing a 'gravitational slingshot' to missions to more distant planets in the Solar System.



© NASA



"VOLCANOES HAVE BEEN
OBSERVED ON VENUS, SUCH
AS IDUNN MONS IN THE PLANET'S
SOUTHERN HEMISPHERE"

ATMOSPHERIC COMPOSITION

96.5%
CARBON DIOXIDE

3.5%
NITROGEN

150PPM*
SULPHUR DIOXIDE

70PPM*
ARGON

*PARTS PER MILLION

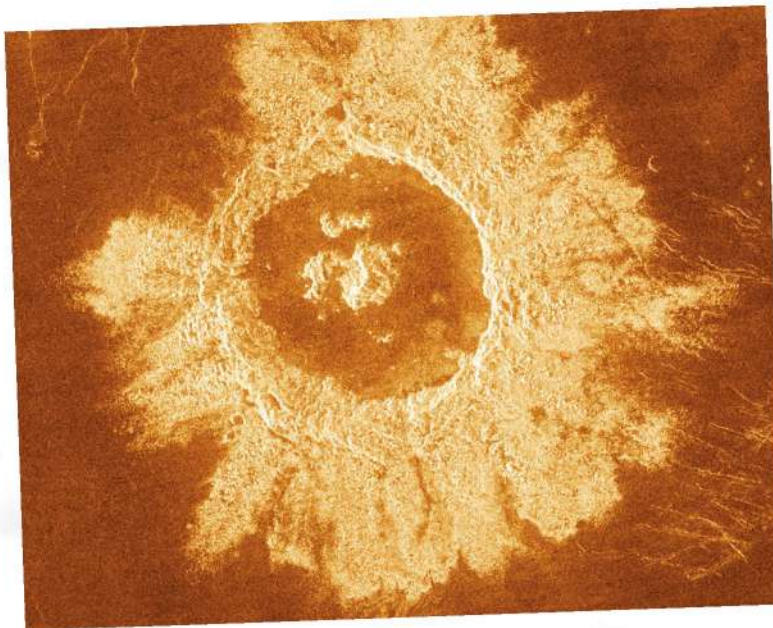
VENUS IN THE NEWS

FORMING CRATERS ON DIFFERENT PLANETS

A recent study has been investigating how meteorites form impact craters – and in particular the features surrounding the craters called ‘rays’ – on extraterrestrial worlds that include Venus. These rays refer to the long, radial streaks that extend out from the centres of the craters out towards their rings. Scientists have been creating analogues to try and understand how these rays form by simply dropping a heavy metal ball onto a sand bed. However, the analogues weren’t revealing the origin of the rays.

When Dr Tapan Sabuwala of the Okinawa Institute of Science and Technology Graduate University in Japan watched online videos of a ball-drop experiment by secondary-school students, he suddenly had a eureka moment. “These experiments are popular in science classes. I noticed that some of their experiments were producing crater rays,” Sabuwala said. But what was the factor creating such features? It was the unevenness of the surface.

Generally, researchers will level out the sand bed during the experiments. However, the messiness of the surface appears to play a part in creating the rays. There have been many depressions and deformed mountain ranges observed on the surface of Venus. Unfortunately, the precise intricacies are still unknown. However, this does give a keen advantage when studying how impact craters are formed on different planets, of which Venus is included.



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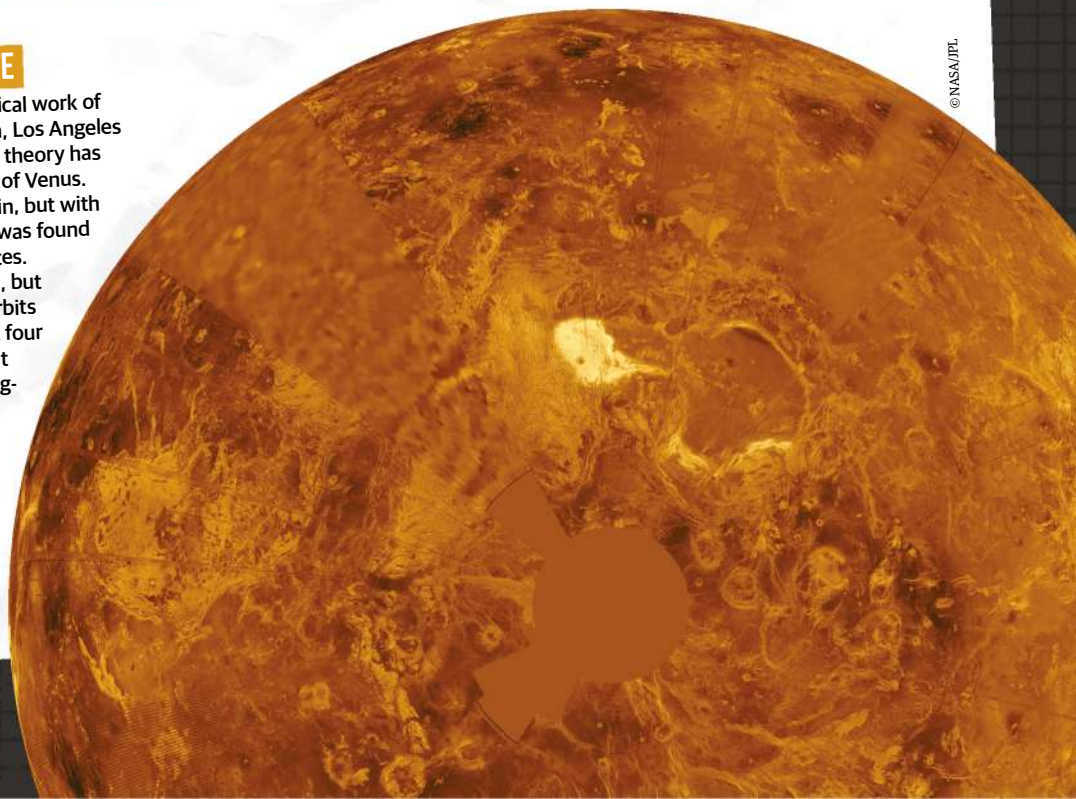
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A PIECE OF VENUS ON EARTH

In a room of the Planetary Spectroscopy Laboratory (PSL) in Berlin, Germany, the German Space Agency has opened a new simulation facility that can bring the conditions of Venus to a laboratory. Because Venus’ thick outer clouds make observations of the ground extremely hard, this facility allows scientists to analyse rock samples at temperatures of up to 1,000 degrees Celsius (1,830 degrees Fahrenheit). There have been many space-based observations of Venus from orbiters, such as the European Space Agency’s (ESA) Venus Express and the Japan Aerospace Exploration Agency’s (JAXA) Akatsuki, but this simulation can provide spectroscopic emission analysis of rock samples in a range of temperatures, as if actually on the surface of Venus. The results will complement the observations taken from the extraterrestrial missions. “PSL took up this challenge, building on nearly a decade of experience in high-temperature emission spectroscopy in the mid-infrared. After several years of development and extensive testing, PSL is now in routine operation for Venus-analogue emissivity measurements from 0.7 to 1.5 micrometres over the whole Venus surface temperature range,” said Jörn Helbert of PSL, who led the development of the new facility.

EXPLAINING VENUS’ WEIRD ROTATION RATE

By combining observational data with the theoretical work of three researchers from the University of California, Los Angeles (UCLA), and Sorbonne Université in France, a new theory has been proposed to explain the varied rotation rate of Venus. It takes Venus 243 Earth days to complete one spin, but with exact measurements made by Venus missions, it was found that this time varies by an average of seven minutes. Scientists have struggled to explain this deviation, but have also noticed that the planet’s atmosphere orbits considerably quicker, completing one orbit in just four Earth days. Astronomers decided to take a look at the possibility of surface mountains carving a long-standing 10,000-kilometre (6,000-mile) wave in the thick atmosphere. On Earth these waves dissipate quickly due to rapid air currents, but Venus’ atmosphere is much thicker. Simulations of this showed that the mountains can cause a two-minute variation in the planet’s spin – not enough to account for the full seven minutes, but enough to suggest that other physical features can cause this variation.



© NASA/JPL

VISITING VENUS

We've sent spacecraft all over the Solar System, and Venus is no exception. The first came in 1962 with NASA's Mariner 2. This was the first successful spacecraft to visit another planet, but the Soviet Venera 7 became the first spacecraft to transmit data from the surface of Venus, for a total of 23 minutes. Venera 7 revealed the planet's scorching surface temperatures and crushing atmospheric pressures. Over a decade later, Venera 13 became the first lander to transmit colour images from the surface of Venus.

However, there was still so much more to learn about this mysterious, boiling planet. NASA sent the Pioneer probes and the Magellan spacecraft to Venus to reveal more of our sister planet's secrets. The ESA had its Venus Express orbiter, which was active between 2006 and 2015, and after a delayed orbital insertion, JAXA eventually placed its Akatsuki orbiter into orbit around Venus in 2015, where it currently remains.

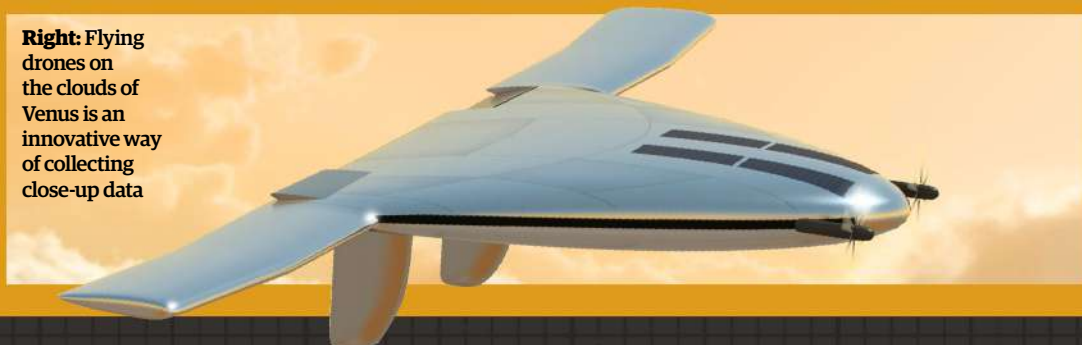
Venus is visited by spacecraft relatively frequently as it's best used as a 'gravitational slingshot',

providing a gravitational speed boost to spacecraft flying towards their next destination. However, scientists and engineers are coming up with new and creative ways of exploring other planets, with NASA even awarding a contract to a drone-specialist company called Black Swift Technologies to develop a drone that can explore the upper atmosphere of Venus. The main reason behind this is that scientists now think that the most ideal conditions for life as we know it to survive on Venus reside in the cloud tops.

EXPLORATION OF VENUS HIGHLIGHTS

- Date:** 27 August 1962
Agency: NASA
Spacecraft: Mariner 2
- Date:** 12 June 1967
Agency: USSR
Spacecraft: Venera 4
- Date:** 14 June 1967
Agency: NASA
Spacecraft: Mariner 5
- Date:** 5 & 10 January 1969
Agency: USSR
Spacecraft: Venera 5 & 6
- Date:** 17 August 1970
Agency: USSR
Spacecraft: Venera 7
- Date:** 8 & 14 June 1975
Agency: USSR
Spacecraft: Venera 9 & 10
- Date:** 20 May 1978
Agency: NASA
Spacecraft: Pioneer Venus 1
- Date:** 8 August 1978
Agency: NASA
Spacecraft: Pioneer Venus 2
- Date:** 15 & 21 December 1984
Agency: USSR
Spacecraft: Vega 1 & 2
- Date:** 4 May 1989
Agency: NASA
Spacecraft: Magellan
- Date:** 18 October 1989
Agency: NASA
Spacecraft: Galileo
- Date:** 15 October 1997
Agency: NASA/ESA
Spacecraft: Cassini-Huygens
- Date:** 3 August 2004
Agency: NASA
Spacecraft: MESSENGER
- Date:** 9 November 2005
Agency: ESA
Spacecraft: Venus Express
- Date:** 20 May 2010
Agency: JAXA
Spacecraft: Akatsuki

Right: Flying drones on the clouds of Venus is an innovative way of collecting close-up data



© Adrian Mann

VENUS BY NUMBERS

TWO

The BepiColombo mission to Mercury underwent two flybys of Venus, the first on 15 October 2020

650 BCE

Observations of Venus can be traced back to Mayan astronomers in 650 BCE, which led to a highly accurate calendar

In the top layer of Venus' clouds, winds can reach up to 360 kilometres (224 miles) per hour – faster than hurricanes on Earth

243

A day on Venus lasts 243 Earth days, whereas a year on Venus only lasts 224.7 Earth days, oddly making a day longer than a year

11 KM

Maxwell Montes, the tallest mountain range on Venus, towers up to roughly 11 kilometres (seven miles) above the surface

Akatsuki was supposed to enter Venus orbit on 6 December 2010. It successfully entered orbit on 7 December 2015

KEY



Flyby



Orbiter



Lander

Instant expert

HOW HIGH UP ARE EARTH'S GROUND-BASED TELESCOPES?

Large observatories are generally built at high altitudes to reduce the effects of the atmosphere that can spoil our view of the universe

Look through a telescope and you'll likely see the view wobble, similar to a heat haze over a hot road. This is caused by the 100 kilometres (62 miles) of air above us, and it significantly affects how well we can see into space. While old Victorian telescopes are often found near cities, the increase in light pollution and growing technological capabilities have led observatories to be built in more remote locations and at high altitudes to reduce atmospheric interference. For example, the British state astronomy program began with the Royal Observatory Greenwich in 1676 and is now carried out by mountaintop telescopes in Hawaii and the Canary Islands.

National observing programs have clustered around a few key mountaintops, where telescopes can share resources. The Roque de los Muchachos on La Palma in the Canaries hosts telescopes and researchers from all over the world. As well as conventional optical astronomy, there are gamma-ray telescopes and a solar telescope - every observation benefits from the reduction in atmospheric interference.

The US and Pacific focus for large telescopes is on Mauna Kea in Hawaii, higher up than La Palma at 4,205 metres (13,796 feet). Gerald Kuiper, who the Kuiper Belt is named after,

first identified Mauna Kea as a good observing location in 1967. He was struck by the image clarity produced by the Apollo missions' telescopes and wanted to find a location on Earth that could obtain similar views. He also considered Chile, and the Chilean Andes are now home to many of the world's most powerful telescopes. The European Southern Observatory's Very Large Telescope is based in Cerro Paranal, bringing four 8.2-metre (26.9-foot) telescopes together as one massive instrument.

The Atacama Large Millimeter/Submillimeter Array and the Atacama Cosmology Telescope are currently among the highest telescopes in the world. The Atacama Desert in Chile is the driest non-Antarctic desert and sits at 5,000 metres (16,400 feet) above sea level, providing observing conditions that are free of light pollution and atmospheric interference.

BIO

ROBIN HAGUE



Hague is the current head of launch

at Skyrora,

coordinating the launch opportunities for Skyrora's vehicles and liaising with UK launch regulators and potential launch sites in addition to coordinating the design and development of Skyrora's small technology demonstration sounding rocket program.

- Optical
- Infrared or near-infrared
- Radio or microwave
- Millimetre and submillimetre wavelengths
- Under construction

THE LEVIATHAN OF PARSONSTOWN

While not located at a high altitude, this was one of the first really large telescopes to be built. It's a Newtonian reflector with a mirror 1.8 metres (5.9 feet) across and was the largest telescope in the world between 1845 and 1917.

LEVIATHAN OF PARSONSTOWN
County Offaly, Ireland

VERKES OBSERVATORY
Williams Bay, Wisconsin

FAULKES TELESCOPE SOUTH
New South Wales, Australia

ANGLO-AUSTRALIAN TELESCOPE
New South Wales, Australia

HALE TELESCOPE
Palomar Mountain, California

HOOVER TELESCOPE
Mount Wilson, California

SOUTH AFRICAN LARGE TELESCOPE
Sutherland, South Africa

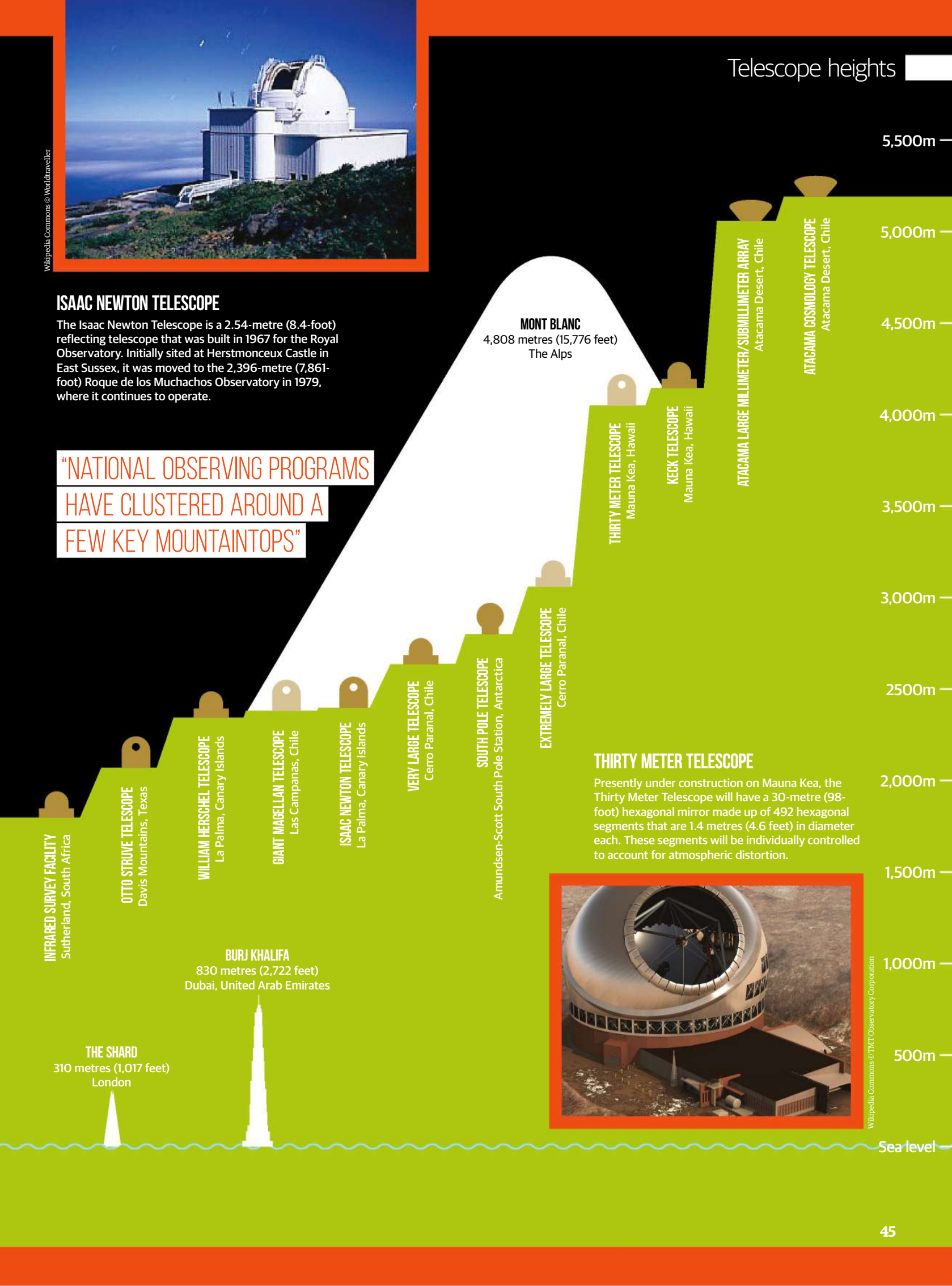




ISAAC NEWTON TELESCOPE

The Isaac Newton Telescope is a 2.54-metre (8.4-foot) reflecting telescope that was built in 1967 for the Royal Observatory. Initially sited at Herstmonceux Castle in East Sussex, it was moved to the 2,396-metre (7,861-foot) Roque de los Muchachos Observatory in 1979, where it continues to operate.

"NATIONAL OBSERVING PROGRAMS
HAVE CLUSTERED AROUND A
FEW KEY MOUNTAINTOPS"



THIRTY METER TELESCOPE

Presently under construction on Mauna Kea, the Thirty Meter Telescope will have a 30-metre (98-foot) hexagonal mirror made up of 492 hexagonal segments that are 1.4 metres (4.6 feet) in diameter each. These segments will be individually controlled to account for atmospheric distortion.





WELCOME TO THE STELLAR AFTERLIFE

They're hot, they're small and technically they're dead. Meet the stellar remnants that have a multimillion-year-long tale to tell

Written by Gemma Lavender

When stars like our Sun have burnt themselves out, they shed their skins to leave behind a dead core. These stellar remnants are white dwarfs, pint-sized objects that are quite unlike any other. No bigger than Earth in diameter, they're white-hot and slowly cooling as they fade away over billions and trillions of years. Eventually they become stellar ghosts - mere shadows of their former selves. 97 per cent of stars in the universe will one day turn into white dwarfs. In the cosmos' far future you would be hard-pressed to find a star that's burning with the aid of fusion, as the universe becomes littered with stellar corpses.

White dwarfs are made by stars that are under eight times the mass of the Sun. Stars that are any larger explode as supernovae, instead leaving behind a dark neutron star or an even darker ravenous black hole. In contrast, white dwarfs are fiery members of the stellar underworld, with temperatures over 200,000 degrees Celsius (360,000 degrees Fahrenheit) when they're born. But if they're dead, how can they be so hot? Astronomers believe that they get their

incandescent heat because they used to be the cores of stars - the industrious powerhouses where lighter elements are burned and transformed into something heavier.

When a star is created in a nebula, it collects hydrogen gas with its gravity until the gaseous ball of the star is both hot and dense enough to erupt into life. Intense heat and light burst from its centre, driven by nuclear fusion reactions that turn hydrogen gas into helium. A star like the Sun has enough hydrogen to fuse into helium for about 10 billion years, and it's already nearly halfway through that. If we travel through time to see the final phase of our Sun's life, we'll see it start to run out of hydrogen. As a result, the centrepiece of our Solar System will begin to change. The nuclear fusion will no longer be able to continue as strongly at its heart, causing the Sun's insides to shrink.

It's not completely over for our Sun though, as its outer layers will still have the will to fight. They'll become hotter, taking

"97 PER CENT OF STARS IN THE UNIVERSE WILL ONE DAY TURN INTO WHITE DWARFS"

over from the core to start nuclear reactions. A huge amount of energy will pour out from the Sun's outer envelope, causing it to expand into a monstrous red giant star whose swollen limbs will push further and further out into space. Here the two parts of the Sun will go in opposite directions. In a final push, the red giant puffs off its ruddy outer layers into a beautiful planetary nebula, which under the scrutiny of different wavebands glow in a myriad of colours.

Meanwhile, the core continues to contract as its fusion grinds to a halt, getting smaller and smaller until it reaches a limit called electron degeneracy pressure. Matter is so dense here that the subatomic particles known as electrons cannot pack together any tighter. The size white dwarfs reach before electron degeneracy pressure kicks

in is about the size of a rocky planet like Earth. Neutron stars, created in supernovae, are even smaller - about the size of a city.

Turn a telescope to a planetary nebula and the white dwarf sitting at its heart can often be seen. However, over the course of a few tens of thousands of years, this star is left behind alone as what remains of the red giant's bulk dissipates into nothingness. Not all white dwarfs are completely alone in space, however. Some cluster together, while others are not too far from us - astronomically speaking at least.

Sirius B, which rests 8.6 light years away and orbits Sirius, the brightest star in the sky, is our closest example of one of these ancient stars. While you can see Sirius blazing away in the constellation of Canis Major with the naked eye,

you won't be able to see Sirius B without the aid of a telescope, and even then it's still a challenge to spot. Being in a constellation that resembles a great dog, we know Sirius as the Dog Star, which means little Sirius B is affectionately known as its Pup. Free of Earth's atmosphere and the interference it can cause, the Hubble Space Telescope has snapped the best image of this binary.

Although Sirius and its Pup look like they are within touching distance of each other when we gaze at them, in reality their elliptical orbit takes them from 8 to 32 times the distance between Earth and the Sun. Because there are more double stars in the Milky Way than single ones, more often than not white dwarfs find themselves in binary systems like Sirius. These are much more lively than their companion stars - having not yet reached the white dwarf stage - and are still creating energy by fusing hydrogen in their cores. Interestingly, sometimes pairs get so close that they begin to spiral into each other, and this is when the cosmic fireworks really start.

Imagine two stars, a happy stellar couple, with one a little more massive than the other. The rules of stellar evolution say that more massive stars use up their hydrogen faster than smaller stars, so one will age faster than the other. The larger star

ANATOMY OF A WHITE DWARF

1 WHITE-HOT ATMOSPHERE

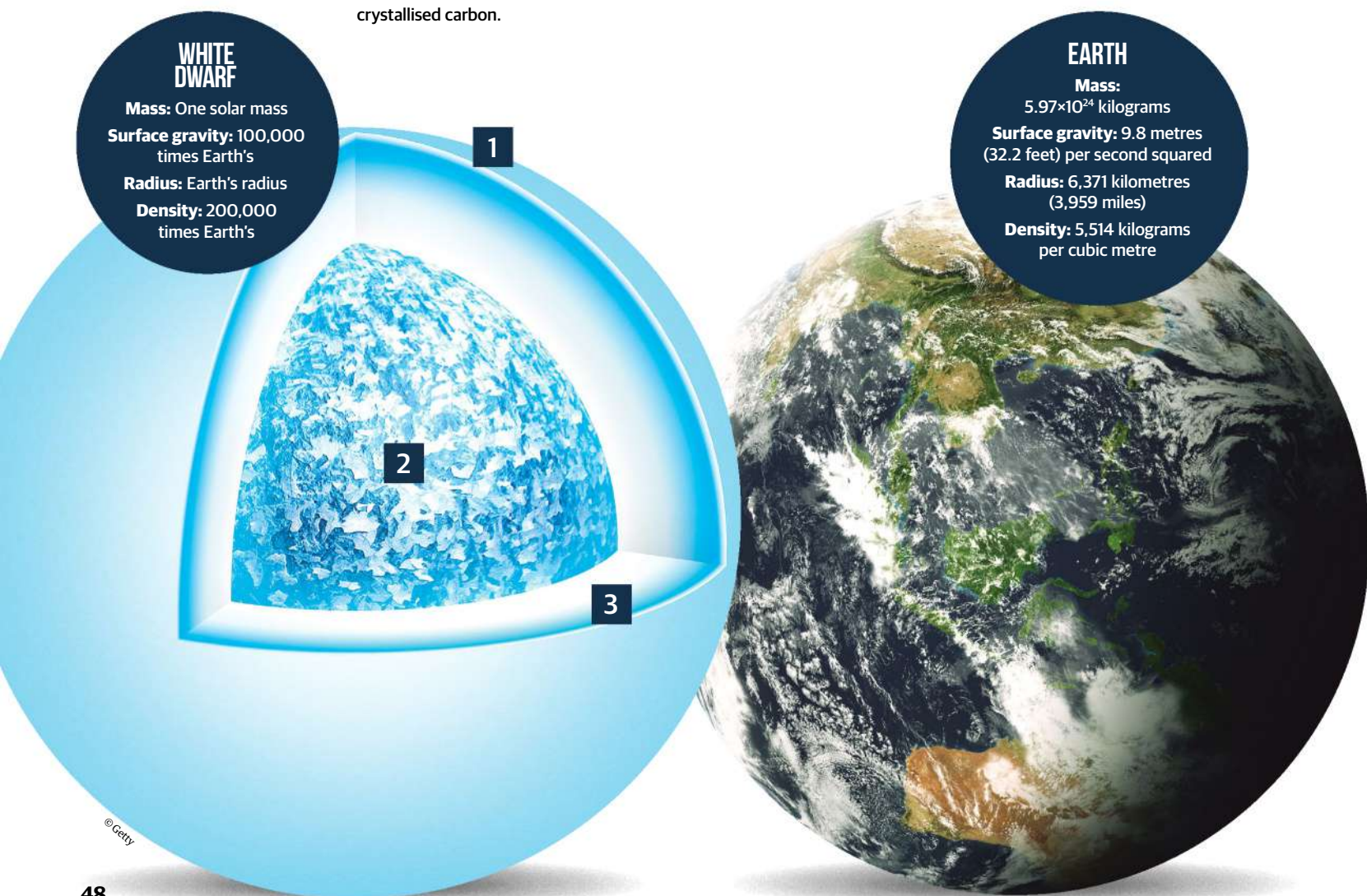
White dwarfs are incredibly hot, hitting temperatures over 200,000 degrees Celsius (360,000 degrees Fahrenheit).

2 CENTRE OF DIAMOND

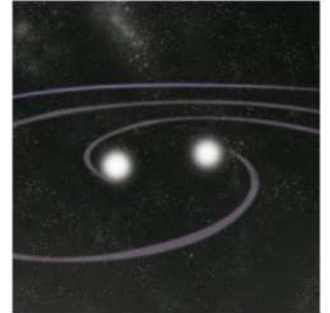
Under low temperatures and high pressures, the crust gives way to a crystalline lattice of carbon and oxygen atoms. This diamond structure is crystallised carbon.

3 A STELLAR CRUST

Below the atmosphere, a crust that's around 50 kilometres (31 miles) thick is thought to exist in many white dwarfs.



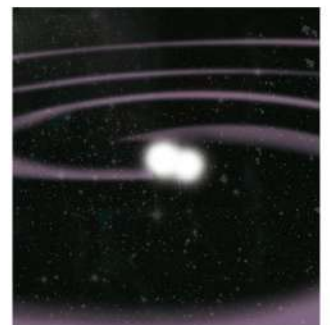
WHEN WHITE DWARFS COLLIDE



Left: The Cat's Eye Nebula has a very complex structure

KICKING UP WAVES

When a pair of white dwarfs steadily spiral towards each other, they churn up the sea of space-time. This creates gravitational waves that become more and more intense as the stars accelerate faster and faster.



READY TO MERGE

As they speed up, the white dwarfs' orbits shrink, bringing them closer together. As they steadily spiral inward, they churn the sea of space-time further and release more gravitational waves.



A GREAT COLLISION

If a pair of white dwarfs are 80,500 kilometres (50,000 miles) apart, it will take thousands of years for them to merge. When they meet, a great explosion called a Type Ia supernova will occur.

"WHITE DWARFS ARE MORE THAN HALF A MILLION TIMES DENSER THAN THE SUN AND THEIR GRAVITY IS STRONG"

goes through the motions of its evolution, leaving a white dwarf behind. Its companion star gets a front-row seat through the entire transition, yet happily continues as a normal star. Astronomers believe that they've seen evidence of such an event - where two stars can be seen inside a planetary nebula. Having a companion star makes these beautiful objects all the more extravagant since the partner interacts with the gas shed by the red giant, creating a double-lobed shape.

However, the companion star isn't immune to feeling the effects of time. Eventually it too will get old, run out of hydrogen in its core and evolve into a red giant, then a white dwarf. White dwarfs are small but aren't lightweights - Sirius B packs in almost as much mass as the Sun has into an object the size of a planet. White dwarf stars are more than half a million times denser than the Sun and their gravity is very strong. A matchbox filled with material scooped off the surface of a white dwarf would have a mass of over 20 tonnes.

When a white dwarf and a companion red giant are close, the white dwarf can sometimes find itself within the outer atmosphere of its monstrous neighbour. It then starts to accumulate matter from it, pulling extra material onto its surface. This matter gathers in very dense pools that become so compact and get so hot that they actually ignite in a thermonuclear explosion on the dead star's surface. Such eruptions are so bright that

we can see them from Earth. Yet despite such a catastrophic force, the white dwarf survives. It isn't put off and proceeds to gather more mass to do it all over again, with explosions happening on a regular basis. This ancient star will eventually pay a price because of its continual need to steal from its companion.

Astronomers call this type of white dwarf a cataclysmic variable. One of the most famous of these is the star system RS Ophiuchi, which is 5,000 light years away and has experienced explosions in 1898, 1933, 1958, 1967, 1985, 2006 and 2021. The eventual fate of the white dwarf member of RS Ophiuchi is a doomed one: it

Below: Artist's impression of the RS Ophiuchi binary system shortly after the white dwarf has exploded as a nova next to its red giant companion



Stellar afterlife

will continue to strip so much mass from its companion that it will get increasingly massive and dense. This will result in an explosion of epic proportions - a Type Ia supernova that completely obliterates the star.

This stellar death is different to the supernovae that happen when massive stars collapse and explode. For a start, a Type Ia supernova is extremely reliable - they're always the same luminosity, which makes them easy to compare, and astronomers can accurately judge how far away they are based on how bright they appear to us. Scientists call them standard candles, which are used to study how dark energy is causing the expansion of the universe to speed up, carrying galaxies and the supernovae in them farther away from us. The reason Type Ia supernovae appear with the same brightness is because they always explode at the same mass, which is 1.44 times that of our Sun. This is called the Chandrasekhar limit, after the Indian astrophysicist.

Not all white dwarfs are thieves, however. Some ancient stars aren't interested in stealing all the material they can from their companion, at least not great amounts. Some prefer the quieter, more simplistic route, seeing out their years by steadily and slowly cooling down. These old stars will get to see their companions evolve as they gradually morph into more white dwarfs. We're now seeing double: two white dwarfs circling each other in a stellar tango.

This can be a dance to the death though. If the white dwarf's orbits are perturbed, perhaps by the changing gravitational field of the red giant before it disappeared, the white dwarfs can start to spiral into one another. As they get closer and closer they begin to unleash gravitational waves, which are ripples in the fabric of space-time disturbed by the proximity at which these two dense partners are dancing. They get closer and closer until they suddenly crash into each other, sparking another supernova.

Right: Hubble uncovered a collection of ancient white dwarf stars in 2002



HOW STELLAR CORPSES ARE MADE

1 MAIN SEQUENCE

A star burns hydrogen during this phase, which lasts most of its life.

2 RED GIANT

Once hydrogen burning stops and helium burning starts, the star bloats.

3

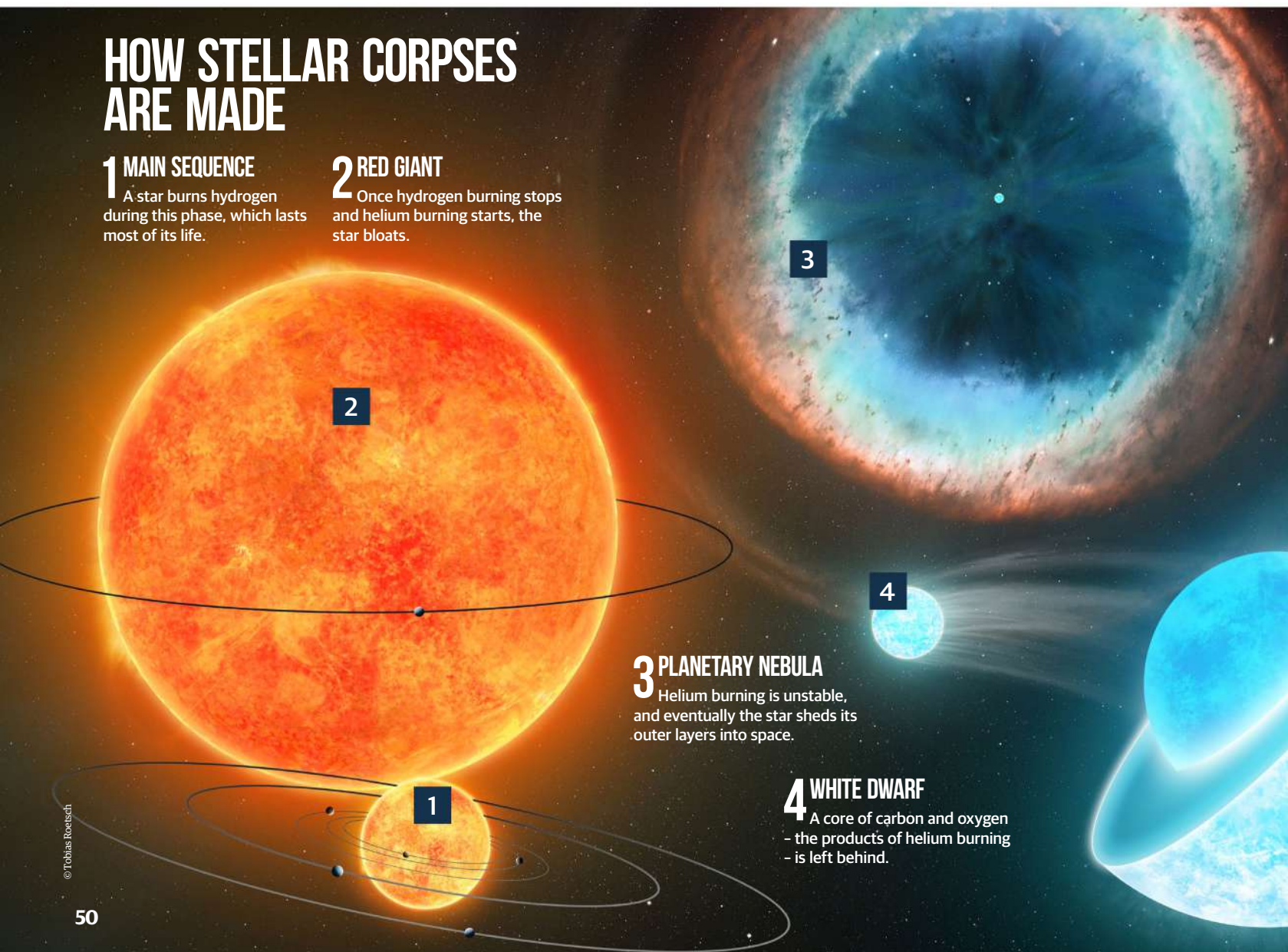
3 PLANETARY NEBULA

Helium burning is unstable, and eventually the star sheds its outer layers into space.

4

4 WHITE DWARF

A core of carbon and oxygen - the products of helium burning - is left behind.





the same type of dust we are seeing in these star systems," said Michael Jura of the University of California, Los Angeles. "This tells us that the stars have asteroids like ours - and therefore could have rocky planets."

In 2013 astronomers at the University of Cambridge used the Hubble Space Telescope to find asteroidal material actually polluting the surface of white dwarf stars in the Hyades star cluster, which is 150 light years away in the constellation of Taurus. The astronomers detected the chemical fingerprints of carbon and silicon at ultraviolet wavelengths. These elements are the building blocks of rocky planets and are very commonly found in asteroids.

If asteroids can survive the death of a star, at least until they fall onto the white dwarf and are pulverised, can planets also be found around white dwarfs? "When these stars were born, they built planets, and there's a good chance that they currently retain some of them," explains Jay Farihi, who was the leader of the 2013 study. "The signs of rocky debris we are seeing are evidence of this - they're at least as rocky as the most primitive terrestrial bodies in our Solar System. Based on the silicon-to-carbon ratio we found, we can actually say that this material is basically Earthlike."

Even if rockier planets are destroyed during the red giant phase of a star, some astronomers still think that new worlds could form from the debris of the planetary nebula. But the fate of any outer planets that manage to survive a red giant phase is unclear.

Astronomers haven't yet confirmed any planets in the habitable zone of a white dwarf, but there's a race among competing teams to be the first to find one. If a planet could be found in the habitable zone around a white dwarf, where the temperature would be just right for liquid water - though this would have to be very close to the white dwarf - it's possible that something could live on that planet. If this turns out to be the case, it would have many implications for our understanding of the universe's future - proving once and for all that there is life after stellar death.

"THEY GET CLOSER
AND CLOSER UNTIL THEY
SUDDENLY CRASH INTO
EACH OTHER, SPARKING
ANOTHER SUPERNOVA"

This won't happen to the Sun's white dwarf because our star doesn't have a stellar companion. Instead it will live out the rest of time lonely, slowly cooling over thousands of trillions of years. Eventually our star will get so cold that it won't glow at all, becoming a dark, inert lump of dead stellar material called a black dwarf. Black dwarfs are only theoretical at this moment in time, because the universe isn't old enough for even the most ancient white dwarfs to have cooled to become one yet. To put this into context, the Sun's white dwarf will become a black dwarf in a quadrillion years, or a thousand trillion years.

But the Sun's white dwarf won't be completely alone, because it will still have what is left of the Solar System to accompany it in its advanced years. Mercury, Venus and probably Earth will be long gone, a distant memory consumed by the growing red giant that the Sun will evolve into. As the red giant continues to swell, its changing gravitational field will also stir up the planets and the asteroids, causing them to crash into one another and creating an immeasurable amount of debris. All of this planetary debris will linger long after the white dwarf has revealed itself from inside the red giant, when planetary material and asteroids will start to come crashing down into it.

We know this because astronomers have already detected asteroids crashing into white dwarfs. In 2009 scientists used the infrared eyes of NASA's Spitzer Space Telescope to study six white dwarfs, finding the chemical imprint of asteroid material in their light. These asteroids were being pulled apart, broken up into dust by the jostling action created by the white dwarfs' gravity. "If you ground up our asteroids and rocky planets, you would get

Right:
NGC 6751 has
a white dwarf
and rests
6,500 light
years away

©NASA

©NASA



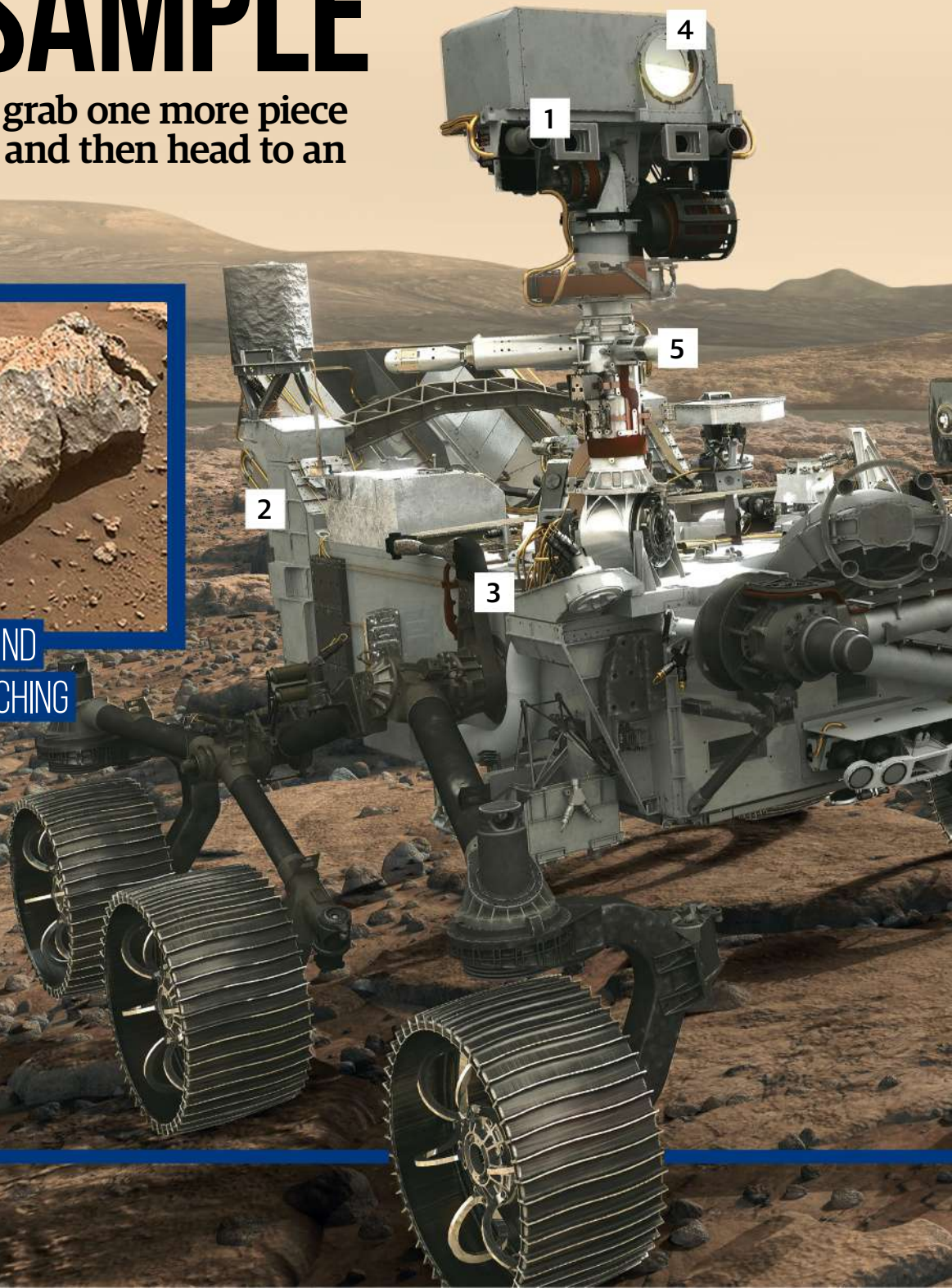
PERSEVERANCE SNAGS ITS SEVENTH MARTIAN ROCK SAMPLE

The Mars rover will grab one more piece from its current site and then head to an ancient river delta

Reported by Mike Wall



"PERSEVERANCE WILL END
UP COLLECTING AND CACHING
SEVERAL DOZEN RED
PLANET SAMPLES"



NASA's Perseverance rover now has seven Mars rock samples in its collection. The car-sized robot drilled into another Martian rock and socked away the resulting core, mission team members announced on 8 March. It's the seventh drilled sample that Perseverance has collected since touching down on the floor of the Red Planet's Jezero crater in February 2021.

Collecting samples for future return to Earth is one of Perseverance's two main tasks, along with hunting for signs of ancient Mars life. The 45-kilometre (28-mile) Jezero crater harboured a lake and a river delta in the ancient past, so it's a great place to do such work.

Here on Earth, river deltas are good at preserving signs of life as we know it, as well as life's basic building blocks - carbon-containing organic compounds. Perseverance team members are therefore eager to explore remnants of the Jezero delta, and they plan to do so soon. "I plan to get one more sample here before heading on

towards the ancient river delta," the rover team said in a tweet, assuming the voice of Perseverance.

Perseverance spent its first Earth year on Mars exploring the crater floor to the south and west of its landing site, which was named after science-fiction author Octavia Butler. The rover is now heading back towards the touchdown zone on its way to an accessible segment of the ancient delta. The Perseverance team is planning the rover's route with the help of Ingenuity, the 1.8-kilogram helicopter that landed with Perseverance last year. Ingenuity aced its original mission, a five-flight technology-demonstrating campaign, and is now scouting terrain for the rover on an extended mission. Ingenuity has flown 20 times on Mars to date and is still going strong. If all goes according to plan, Perseverance will end up collecting and caching several dozen Red Planet samples. This material will be brought to Earth, perhaps as early as 2031, by a joint NASA-European Space Agency mission campaign.

PERSEVERANCE'S INSTRUMENTAL SUITE

This investigative arsenal will reveal remarkable things about ancient Martian life and habitability

1 MASTCAM-Z

Its objective is to take high-definition videos, panoramic colour and 3D images of Mars, with the added ability to zoom in on distant objects.

2 RADAR IMAGER FOR MARS' SUBSURFACE EXPERIMENT (RIMFAX)

Designed to see beneath the surface, RIMFAX will use ground-penetrating radar to detect underground geological features.

3 MARS OXYGEN IN-SITU RESOURCE UTILIZATION EXPERIMENT (MOXIE)

This experiment will test if we can produce oxygen from Mars' carbon dioxide-rich atmosphere. This will have implications for the production of breathable oxygen and rocket propellant on other worlds.

4 SUPERCAM

SuperCam will search for signs of ancient life by analysing the chemical composition of rocks and soil to the degree it can identify their atomic and molecular make-up.

5 MARS ENVIRONMENTAL DYNAMICS ANALYZER (MEDA)

The local weather will be analysed with MEDA, including wind speed and direction, humidity, temperature and dust in the atmosphere.

6 PLANETARY INSTRUMENT FOR X-RAY LITHOCHEMISTRY (PIXL)

PIXL includes an X-ray spectrometer that will identify the chemical elements residing in rocks in incredibly precise detail.

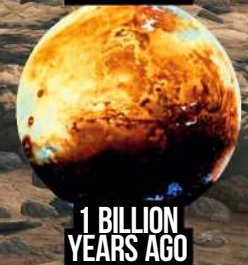
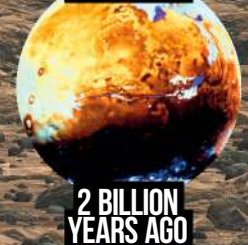
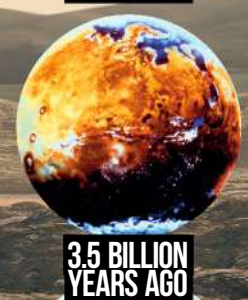
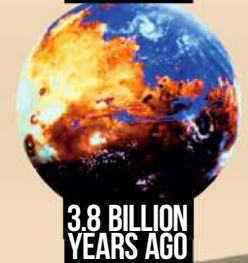
7 SCANNING HABITABLE ENVIRONMENTS WITH RAMAN AND LUMINESCENCE FOR ORGANICS AND CHEMICALS (SHERLOC)

Consisting of spectrometers, a laser and a camera, SHERLOC will search for minerals, organic molecules and potential biosignatures in Jezero crater.



THE HISTORY OF WATER ON MARS

Evidence suggests that Mars was once covered in oceans



© Alamy



WHERE HAVE THESE GIANT FILAMENTS COME FROM?

Mysterious magnetic filaments have been found at the heart of the Milky Way, but astronomers are still trying to discover their origin

Reported by David Crookes

In 1984, astronomer Farhad Yusef-Zadeh was observing the night sky when he spotted something rather unusual that stopped him in his tracks. He had been working on his PhD at Columbia University, attempting to figure out the nature of compact sources. But along with colleague Don Chance and University of California at Los Angeles professor Mark Morris, he helped identify three large arcs some 150 light years long.

At first they couldn't believe what they were seeing. Though the existence of filaments had been proposed by Swedish plasma physicist Hannes Alfvén and later proven, nobody other than him thought these one-dimensional strands would stretch to such lengths. Even Yusef-Zadeh, now of Northwestern University in Illinois, wasn't trying to prove the existence of filaments. "We were trying to figure out the nature of compact sources in this region," he says.

But here was a small team staring at potential proof - a discovery made using the Very Large Array (VLA), the world's most widely used radio telescope, located 80 kilometres (50 miles) west of Socorro, New Mexico. "It was an accident," Yusef-Zadeh recalls. "It turned out the compact sources - expected to be HII regions associated with star formation - were peaks of extended filamentary structures. But since this type of structure hadn't been seen before, we were suspicious that they were real."

Left: As well as being able to see the bubble discovered in 2018, this image shows the black hole Sagittarius A*, as well as the magnetic filaments

MAGNETIC FILAMENTS BY NUMBERS

1,000

Number of magnetic strands found at the Milky Way's centre

TEN

times more than previously discovered

150

Length in light years

1984

Year they were first observed

200

Hours spent surveying the region using the MeerKAT telescope array

20

Separate radio observations combined

25,000

Distance of the filaments from Earth in light years

0.5

Space between the filaments in parsecs

The trio of parallel filaments were narrow – just a couple of light years thick – but given their prominence and their surprising discovery, they also demanded extra attention. Indeed, the astronomers continued with their work, gathering more evidence until there was no doubt in their minds. “We eventually confirmed our result by detecting the same filaments at multiple frequencies,” Yusef-Zadeh explains, a task that finally ruled out bad data. The discovery had a huge effect, not only on science but on Yusef-Zadeh personally. “The contrast in size scale between compact sources and what we found was huge,” he says. “The direction of my thesis topic changed completely after detecting radio filaments, so I lost a couple of years of work based on my earlier study.”

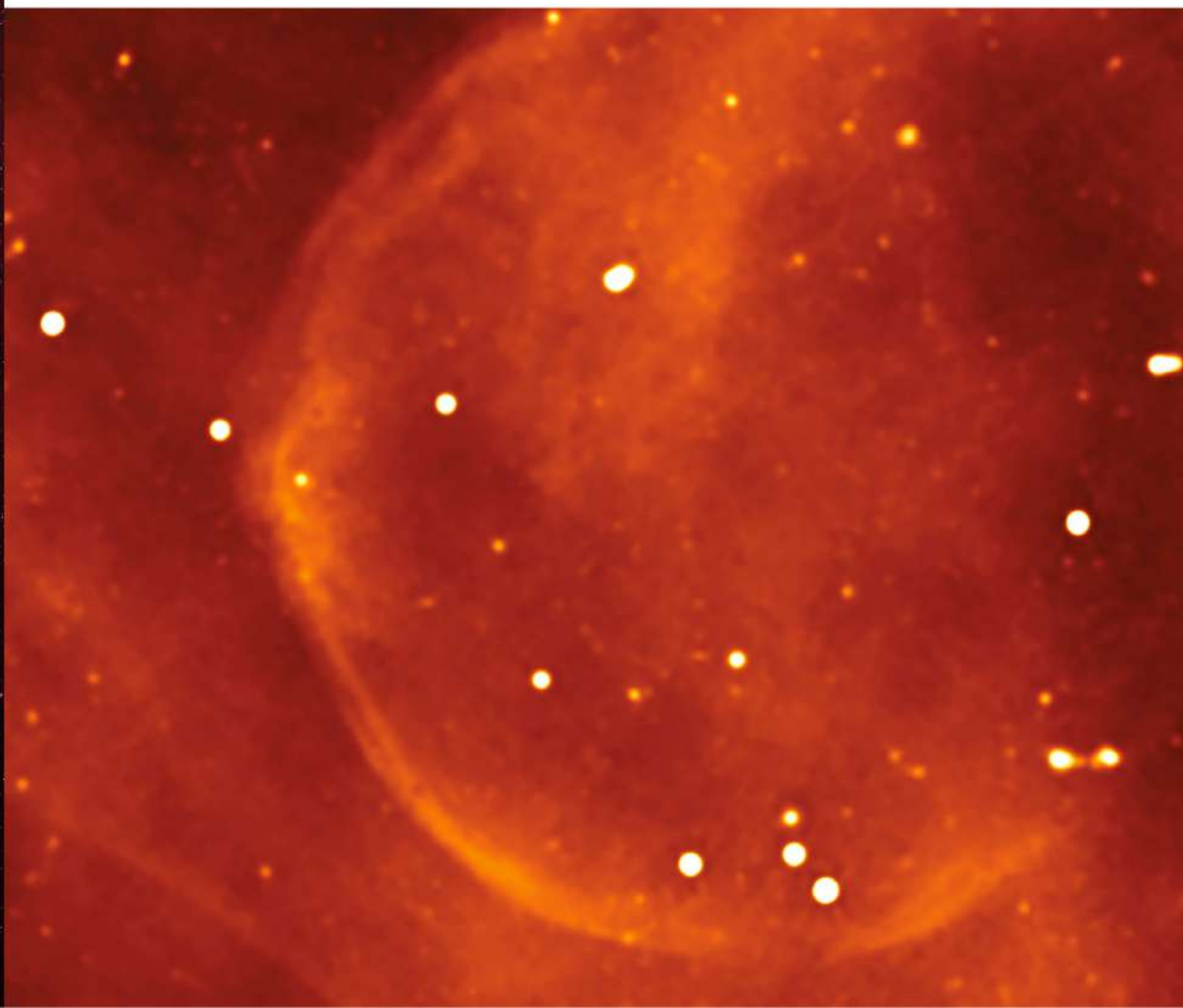
Even so, over the following years, more of these filaments were discovered using the VLA, leaving astronomers ever more intrigued and yet baffled at the same time. “The filaments were mainly directed perpendicular to the galactic plane,” says Yusef-Zadeh. “As such there were no obvious sources powering the filaments, and the morphology was unusual.” It has spawned a long-term mystery that continues to preoccupy Yusef-Zadeh and many others to this day. “There were just no clues as to the origin of these filaments,”

Yusef-Zadeh laments. But he may well be on the verge of a breakthrough in finally discovering just what is causing them, and he's getting very excited at the prospect.

Over time, the filaments have been interpreted as cosmic-ray electrons gyrating the magnetic field at close to the speed of light. Astronomers believed they would provide an insight into the structure of magnetic fields at the heart of the Milky Way, but the question is less what they are and more how they came to be. “There are now a couple dozen theoretical models for the origin of the filaments, but there's no model that's accepted by everyone,” Yusef-Zadeh says.

In that sense the answer remains very much up in the air, and it's still open to debate. “There were models related to stellar sources powering preexisting magnetic structures or there were theories related to turbulent conditions of the interstellar medium in the nucleus of our galaxy,” he says. One of the problems has been having too few filaments to study – numbers that have been counted in the dozens. It has long made it difficult to draw any clear conclusions, and that's proven to be mightily frustrating.

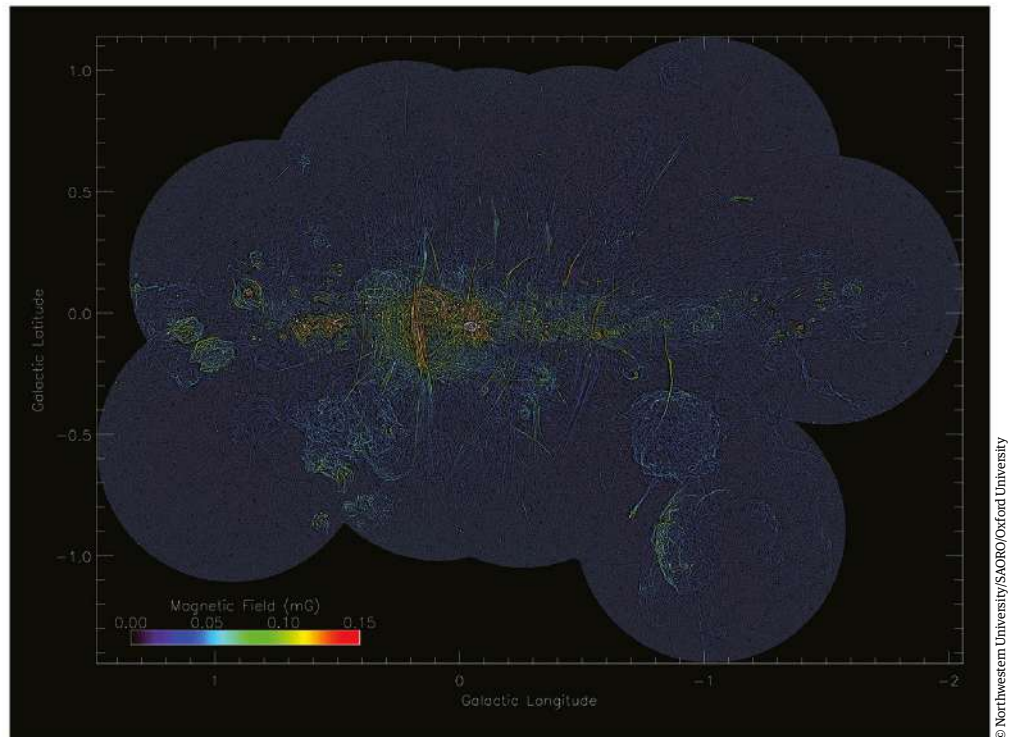
Step forward the South African Radio Astronomy Observatory's MeerKAT radio telescope, which was inaugurated in 2018. Located in the Northern Cape



of South Africa, it consists of 64 antennae spread across a diameter of eight kilometres (five miles). Each dish is 13.5 metres (44 feet) in diameter, and together they make up the most sensitive radio telescope on Earth - just the thing needed to go some way towards clearing up a mystery such as this. "The telescope is a big leap forward," Yusef-Zadeh affirms. "It's new and it has a broad band. It's located in the Southern Hemisphere and it is geographically advantageous to observe the galactic centre for 12 hours a day. In addition, more than 200 hours were spent observing a big region of the sky and three years of processing. The level of dedication, the location and the strategy were different from previous surveys." It has certainly made a massive difference to his study.

Those 200 hours have enabled astronomers to produce a mammoth mosaic of 20 separate observations at radio wavelength covering an area of the sky about 30 times the area of the full Moon. They have given researchers a very clear picture towards the centre of our galaxy, 25,000 light years away, and not only are the filaments clearly shown, it's now evident there are far more than were previously known about.

In fact, the 100-megapixel image is so clear and detailed thanks to MeerKAT's ability to pick up on synchrotron radiation created by the flow



"THE FILAMENTS WERE MAINLY DIRECTED PERPENDICULAR TO THE GALACTIC PLANE" FARHAD YUSEF-ZADEH

Above: With the background removed, this mosaic image allows you to more clearly see the magnetic filaments

Left: A rare spherical supernova remnant found during studies of the filaments

along the length of the strands that it's possible to identify ten times more filaments than previously discovered. That's 1,000 of these mysterious strands, collectively offering a far greater chance of understanding these structures than ever before. "We can see a population of filaments and learn about the statistical properties of them. It's a feat that has not been previously possible," Yusef-Zadeh says.

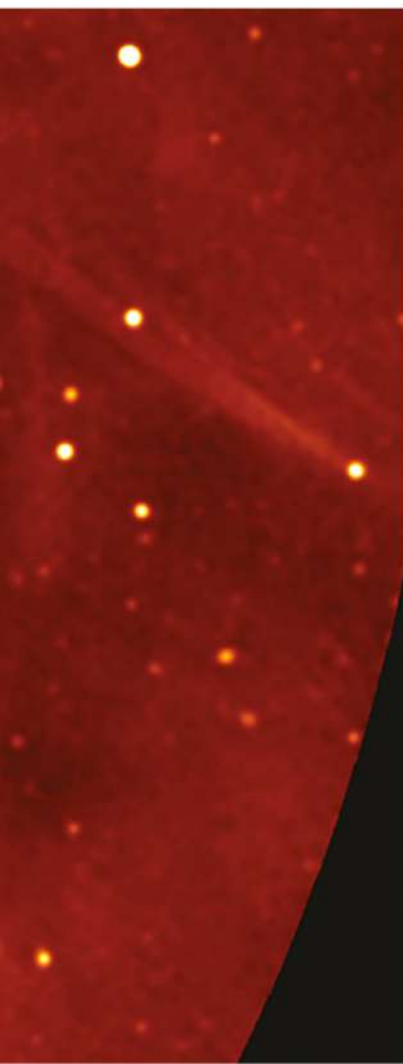
To obtain the best possible look at the filaments, the astronomers removed the background from the main image. This isolated the filaments from their surrounding structures, and it's made some very clear patterns plain to see. For example, the filaments that were discovered decades ago were found in pairs and clusters, and nothing in the new data suggests any departure from that. Instead the image is so clear, the filaments are very noticeably stacked and equally spaced, in a manner described by the researchers as being like strings on a harp. "We are learning about spacing between filaments and looking to explain the origin of filamentation with pronounced spacing in the context of an instability in the interstellar medium of the galactic centre," Yusef-Zadeh says.

The filaments also possess a magnetic field that is much higher than expected from the galaxy - something noted in the study published in *The*

Astrophysical Journal Letters. "By studying the magnetic fields you learn about the energetics, the spectrum of cosmic-ray particles and the strength of the magnetic field," he continues. "All of these are related to physical properties of the filaments so that a theoretical model can explain these properties. The goal is to understand processes that can accelerate particles to relativistic energies."

There are some clues. Yusef-Zadeh has previously found that radio waves are generated from the filaments when high-energy cosmic-ray particles collide with the filaments' magnetic fields and gyrate at close to the speed of light. But the problem here is that no one knows where those high-energy cosmic-ray particles are coming from. There was a chance that the source could have been shared by a recently discovered supernovae, but more detailed studies have ruled this out - it appears that the wavelengths of light emitted by the filaments are varying to a greater degree than the wavelengths coming from the remnants of the supernova, pointing towards a different origin.

If anything, the researchers say, the filaments are more likely to be related to the past outburst activity of our galaxy's central supermassive black hole, Sagittarius A*. Intriguingly, they may also be related to giant radio-emitted bubbles hundreds of light years tall which were found dwarfing other



"LENGTH DISTRIBUTION IS NEXT ON THE LIST OF MYSTERIES THAT WE WANT TO RESOLVE IN RELATION TO THE FILAMENTS" FARHAD YUSEF-ZADEH

structures at the centre of the Milky Way in 2019 by, among others, Yusef-Zadeh. "It's complicated to explain, but mainly this idea requires a large-scale wind - one that's likely produced by high cosmic ray pressure in the galactic centre," he explains. "In this theory, this wind is also producing the bubble."

According to the paper, which is also authored by Oxford University astrophysicist Ian Heywood, the triggering event would be enhanced accretion onto the black hole or a burst of star formation several million years ago. Our black hole has a tendency to become uncharacteristically active.

Still, such a theory is far from being confirmed, and more studies are needed. The researchers also say they want to discover why the filaments are so well structured and separated. "If you look at a large number of filaments statistically, those that lie next to each other have an ordered spacing between them of about 0.5 parsecs," Yusef-Zadeh says of a distance about equal to that between the Sun and Earth. In that sense it would appear that the mysteries just keep stacking up, ensuring the filaments are sure to be studied for many more years to come.

In fact, researchers say that they're keen to discover whether or not the filaments move or change over time. They also want to know what causes the electrons to accelerate at great speeds. "Then there's the length distribution, which is next on the list of mysteries that we want to resolve in relation to the filaments," Yusef-Zadeh tells *All About Space*. "We want to know why some filaments are longer and some are shorter; we want to know what the distribution is and we want to discover how they are related to the strength of the magnetic field and to the spectrum of cosmic-ray particles."

For now work continues in cataloguing and observing the filaments so that the researchers have a database logging the magnetic field, spectrum, curve, angle and intensity of each one of them. The more the astronomers can find out about the filaments, the greater the chance they have of working out just where they came from. In

TAKING A SNAPSHOT OF THE GALACTIC CENTRE

This stunning image taken by MeerKAT gives us a detailed look at the Milky Way's central region

1 DIFFERENT COLOURS

This mosaic of 20 images shows radio emissions from the centre of the Milky Way. The colours indicate the signal's strength, with red and orange being strongest and the weakest being light grey.

2 GALACTIC PLANE

The main structure you can see is the bright galactic plane, running horizontally and packed with stars.

3 SUPERNOVA REMNANT

The MeerKAT telescope array picked up on many different structures, including this supernova remnant - the shell left behind when a massive star explodes.

4 SUPERMASSIVE BLACK HOLE

This is the supermassive black hole Sagittarius A* - a bright and compact astronomical radio source that's 4 million times the mass of our Sun.

5 MAGNETIC FILAMENTS

One of the most exciting aspects of this image is the sheer number of magnetic filaments running through it.



that sense they are far closer than ever before. It may have taken 35 years, but as Yusef-Zadeh says, these things take time.

And that's not all. The image generated using data from MeerKAT has also thrown up other phenomena. As well as new supernova remnants, the clear imagery shows outbursting stars, stellar nurseries and other compact radio wave sources that likely show supermassive black holes outside of our galaxy. It's a mosaic that's sure to be pored over by many different teams for a long time to come. Both this and MeerKAT have the potential to clear up other great mysteries, and it'll be exciting to see what comes next.



David Crookes

Science and technology journalist

David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.



© Northwestern University/SAO/Oxford University



Above: The magnetic filaments in this image look broken

WHERE DID THE MAGNETIC FILAMENTS ORIGINATE?

We know they exist, but their origin remains a mystery

BURSTS OF SUPERNOVAE

There's a possibility that the filaments are due to coordinated outbursts of energy from supernova explosions, but astronomers say this is very unlikely. Radiation emitted from the filaments has different variations from supernova remnants, so the origins are likely different too.

PAST BLACK HOLE ACTIVITY

It's more likely the filaments are related to our supermassive black hole, Sagittarius A*. The team are tracking energetic sources of cosmic-ray particles radiating in the radio band. Time stamping matches the particles to a period of black hole outburst.

BUBBLES OF GAS

There are two enormous radio-emitting bubbles, shaped like an hourglass, inflating from a black hole outburst which may have occurred up to a million years ago. Discovered by MeerKAT in 2018, the radio bubbles may have interacted with star formation to create the filaments.

© I. Heywood/Sarao

BLACK HOLE BILLIARDS

Around these behemoths, smaller black holes weirdly collide

Reported by Meghan Bartels

Take three black holes and throw them into the disc surrounding a supermassive black hole and things get weird. That's the conclusion of new research digging into a particularly strange gravitational-wave event that scientists observed in May 2019. Gravitational waves are the ripples in space-time caused by, among other dramatic events, the mergers of black holes. But this particular observation didn't match other collisions scientists have caught: it resulted in a black hole in the mid-size range that scientists can barely see, much less explain, and some force was stretching the typically circular dance as the behemoths approached each other.

"The gravitational-wave event GW190521 is the most surprising discovery to date. The

black holes' masses and spins were already surprising, but even more surprising was that they appeared not to have a circular orbit leading up to the merger," said Imre Bartos, a physicist at the University of Florida and coauthor of the new research. Astronomers name gravitational-wave signals with the date they were observed, so GW190521 marks a gravitational wave detected on 21 May 2019.

Even in the earliest analysis of the strange signal, scientists suspected that the merger occurred in a pocket of space rich with black holes. Astronomers know of two types of black holes. Stellar black holes form from dying stars and contain perhaps a dozen times the mass of our Sun. Supermassive black holes, in contrast, hide at the centres of some galaxies, including

our Milky Way, and can contain millions of times the mass of their puny counterparts.

The result of the May 2019 merger appeared to be an intermediate black hole, a size category that ranges from perhaps 100 to 1,000 times the mass of our Sun. Scientists had not yet managed to study one and could not explain how such an object might form. In response to the detection, astronomers suggested that one of the colliding black holes was itself the result of a collision, pushing the final product into the mysterious intermediate range at 142 times the mass of the Sun. To get two sequential collisions, the astronomers first analysing GW190521 proposed that the event occurred near what scientists call an active galactic nucleus - a particularly dynamic supermassive black hole

BLACK HOLE COLLISIONS

How gravitational waves form and how they're detected on Earth

1 WHAT IS GRAVITY?

On forming his theory of general relativity, Einstein revealed that gravity is the result of celestial objects distorting the fabric of the universe, which he called space-time, around them.

2 WHAT ARE GRAVITATIONAL WAVES?

Really massive objects, like black holes, create a dent in space-time. This 'dent' doesn't produce gravitational waves, but if two black holes spiral towards each other they will lose energy, sent out as ripples in space-time.

3 WHERE THE SIGNAL COMES FROM

Black holes move closer and begin to merge millions of light years away from Earth.

4 A PULSE OF WAVES

The new, combined black hole settles down; the waves it releases radiate out through space at the speed of light.

5 JOURNEY THROUGH SPACE

The waves then begin their million light year journey to Earth, waiting to be detected.

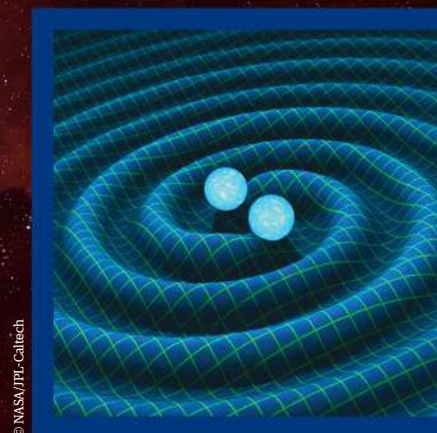
anchoring a galaxy, where smaller black holes might proliferate.

The new research supports that suggestion, approaching the situation from a different angle. These scientists wanted to understand how it was that the two black holes weren't actually circling each other as they collided; instead their orbits were eccentric or elliptical - more ovals than circles. Astronomers thought that the massive gravitational forces involved when two black holes are colliding should have forced these two onto circular paths, so physicists behind the new research set about modelling black hole collisions. And while their calculations suggested that three black holes at random were unlikely to result in an eccentric collision, something changed when they considered the environment of an active galactic nucleus.

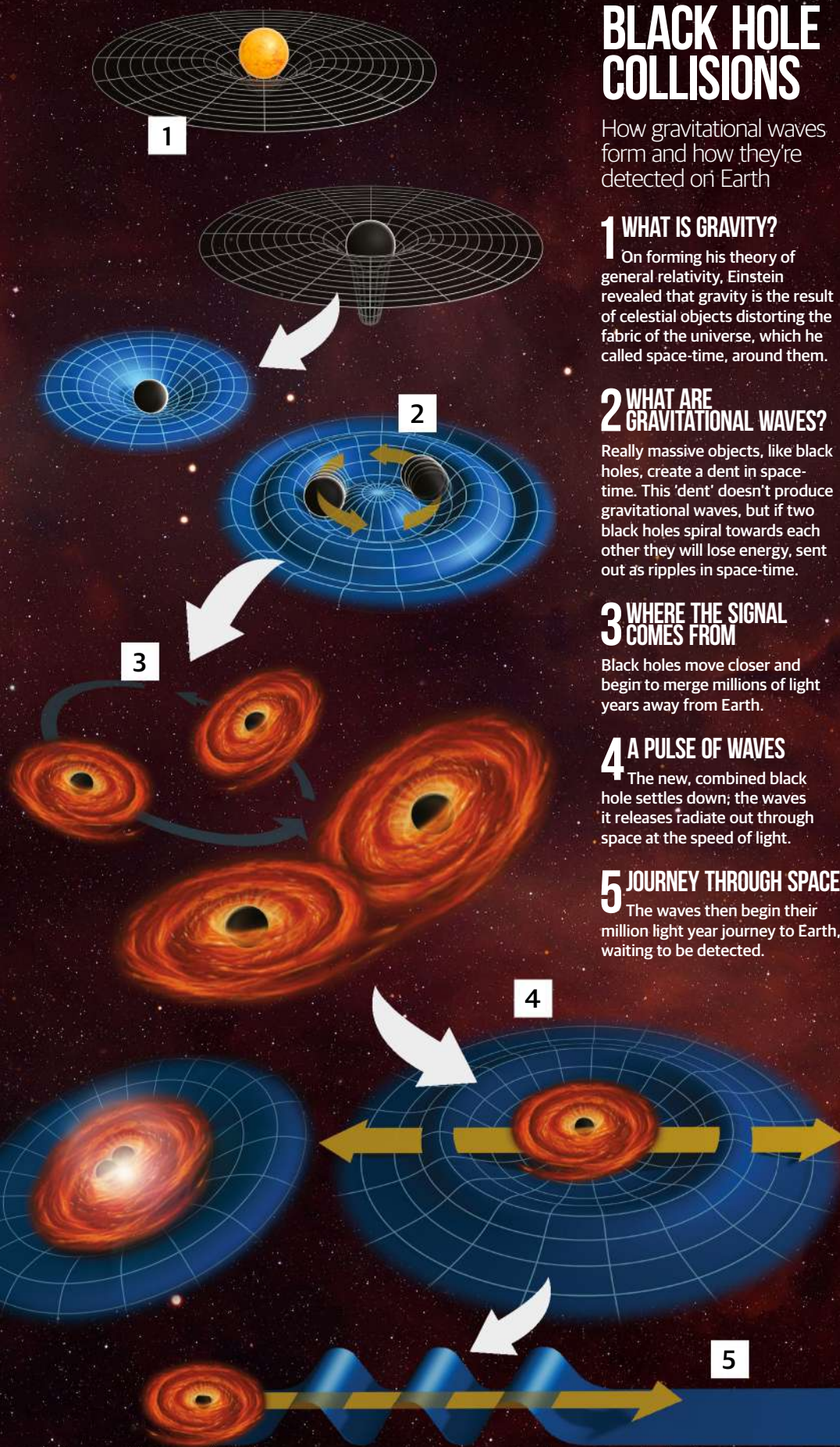
This type of feature also hosts a disc of matter surrounding the supermassive black hole, like a much more massive model of a solar system. Where a solar system has planets, an active galactic nucleus has stellar black holes scattered throughout the disc in what the new research identifies as essentially a two-dimensional system. Under those conditions, the probability of an eccentric merger shot up - as much as 100 times, coauthor Johan Samsing, an astrophysicist at the Niels Bohr Institute in Denmark, said. At that rate, perhaps half of all mergers in the discs of active galactic nuclei would be eccentric rather than circular, making the exceptional observation of May 2019 much less surprising.

"In these environments, the typical velocity and density of black holes is so high that smaller black holes bounce around, as in a giant game of billiards, and wide circular binaries cannot exist," said Bence Kocsis, an astrophysicist at the University of Oxford.

Right: Colliding neutron star or black hole pairs create ripples in the fabric of space-time



© NASA/JPL-Caltech



EXOPLANETS

Would it be possible to survive on a planet around a double-star system?

Tatooine-like planets - planets orbiting around binary stars, also known as circumbinary planets - are no longer just science fiction. The Kepler spacecraft has observed transiting circumbinary planets. Here we focus on circumbinary-type planets that move around the centre of mass of the double-star system in a relatively wide orbit.

The first requirement for survival on a circumbinary planet is that the planet remains dynamically stable. Gravitational perturbations from the binary can destabilise the circumbinary orbit. If this happens then the circumbinary planet is likely ejected from the system, or it could even collide with one of the stars. Both aren't favourable scenarios for survivability. Secondly, if we agree to need liquid water for

survival, and ideally a breathable atmosphere, the circumbinary planet should neither be too close nor too far from the binary.

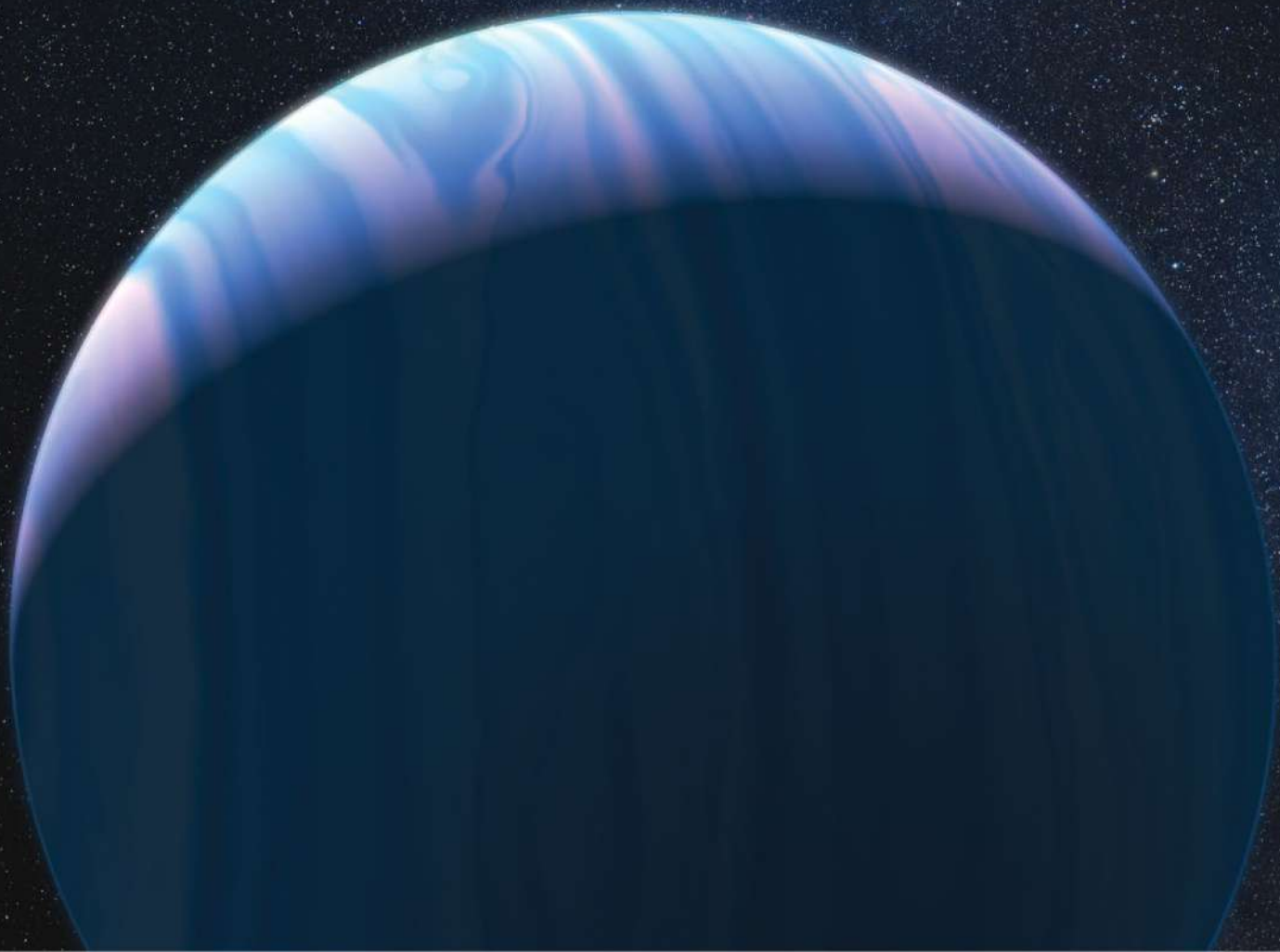
Even if we manage to find a habitable circumbinary planet, it's not guaranteed to stay habitable indefinitely. Over billions of years the binary stars will evolve. In later stages the stars will lose a lot of mass when they evolve to white dwarfs. The mass loss could unbind the circumbinary planet, hurtling it into the darkness of space. If not, the dim light from the white dwarfs would usher in an indefinite ice age. We are fortunate to be living on a planet that



is very accommodating to life.

Adrian Hamers, Max Planck Institute for Astrophysics, Germany

Below: They're nicknamed Tatooine-like planets after the planet from the *Star Wars* films





SOLAR SYSTEM

© NASA, ESA, JPL, Caltech

Did you know?

Ceres is the largest asteroid in the Solar System - it's about 940 kilometres (584 miles) in diameter.

Do you think we should spend more on 'safeguarding' Earth from asteroid impacts?

Those risks are among the few that we can quantify. We know how probable impacts by rocks of different sizes are, and the biggest threat is from the rare big ones. I think if you do a normal calculation working out the probability and the consequences and what insurance premium you should spend to reduce that risk, you come up with a number like £100 or £200 million (\$130 or \$260 million) a year. That's the kind of premium that would be worth spending to reduce the risk of an asteroid impact. It's good that there is talk about doing this and spending money in two different ways.

One way is to do a more complete survey so that we can monitor the orbits of all the asteroids down to about 15 metres (49 feet) across - not just the very big ones - and so be alert to any that might be in orbits that could crash into Earth. The other is to think a bit more about the technology to deflect them if they do get too close. I think it's worth some effort, but that risk doesn't keep



me awake at night.

Lord Martin Rees, British cosmologist and Astronomer Royal

HUNT FOR LIFE

Why haven't we detected other civilisations?

It's a puzzle; we do expect these civilisations to exist. After all, there could be a trillion planets in the galaxy. But there are barriers that need to be cleared if a planet is to host a communicative civilisation. The first is habitability - we need a terrestrial planet in that 'Goldilocks zone' where water flows as a liquid. Abiogenesis - the creation of life from non-life - that's the second barrier. The basic building blocks of life aren't unique to Earth: amino acids have been found in comets, complex organic molecules in interstellar dust clouds, water in exoplanetary systems. The development of technological civilisation is a third barrier. Some say we already share our planet with alien intelligences.

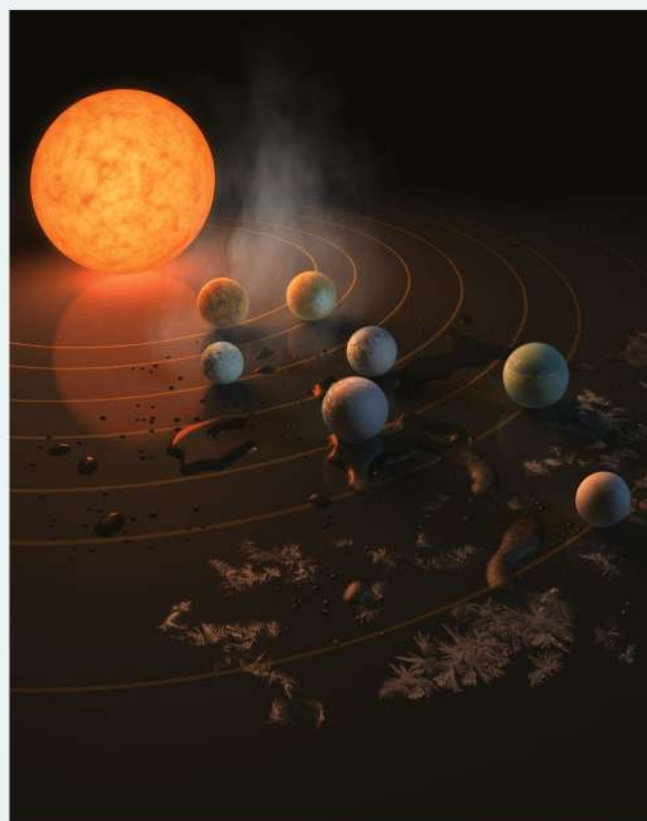
Communication across space - that's a fourth barrier. Maybe advanced civilisations choose to explore inner space rather than outer space, or engineer at small distances rather than large. Or maybe they just don't want to risk an encounter with a potentially more advanced and hostile neighbour. There will be worlds where, for whatever reason, civilisations either stay silent or don't spend long trying to communicate.



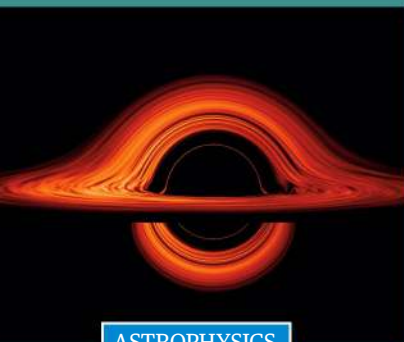
Stephen Webb is a popular science writer

Above: There are a large number of near-Earth objects that could cause harm to our planet

Right: The first barrier is having water exist as a liquid, which is dependant on the distance from a star



© University of Portsmouth



ASTROPHYSICS

What's a photon sphere?

A hundred years ago, Einstein truly became a household name when his theory of relativity was first tested and confirmed by experiments. Einstein predicted that light passing by a massive object should get deflected by gravity, and that this effect could even be detected by measuring the apparent location of stars near the Sun during a solar eclipse. For the Sun this deflection is less than a thousandth of a degree. For a black hole, with its much stronger gravitational field, the light ray can get bent by 360 degrees or more.

Imagine shining a laser pointer at a black hole. If you point it right at the black hole, the light will get swallowed. If you point it to the side, it will get deflected by the black hole's gravity, but still reach your friend on the other side. But as you point the laser closer to the black hole's edge, there's a point where the light just barely doesn't get captured, but also doesn't escape. Instead it just orbits in a perfect circle. This is what we call the 'photon sphere' of a black hole. For non-spinning black holes the photon sphere radius is 50 per cent bigger than the horizon radius, but for rapidly rotating black holes the photon sphere snuggles right up against the horizon, allowing light to orbit many times without falling in and without falling out.



Dr Jeremy Schnittman, Goddard Space Flight Center



Above left: A black hole's gravity alters light coming towards it to create a 'photon sphere'

Above: Asteroid mining could be an extremely profitable business

SPACE EXPLORATION

What can we get from mining asteroids?

If I asked you how many metals you think you have in your pockets at the moment, you might say three or four. But you've probably got around 40 or 50 different metals on you right now if you've got a smartwatch on, a smartphone or even a tablet.

The problem with all those exotic metals is that they are quite rare and hard to get on Earth.

There's a limited supply and they're hard to recycle from the electronics we use. Therefore there's a huge demand and potentially a lot of money to be made by going to the asteroids and mining those as well as mining these resources on Earth.



Lewis Dartnell, professor at the University of Westminster

ASTRONOMY

If Polaris is the North Star, is there a 'south star'?

In the Northern Hemisphere, astronomers are fortunate to have a star, Polaris, very close to the north celestial pole. Polaris appears to stay fixed in position while the constellations rotate around it due to Earth's spin about its axis. It's a sensible assumption that there might be a similar guide at the south celestial pole, the point of sky around which the Southern Hemisphere stars appear to rotate. But Polaris is above the celestial pole purely by chance, and there's no useful beacon marking the south celestial pole. The closest star, Sigma Octantis in Octans, is a very dim, fifth-magnitude star which is extremely hard to make out with the naked eye. While Sigma Octantis is the 'south star', it doesn't have the same usefulness as Polaris for astronomers, so often falls by the wayside. To find the south celestial pole, one way is to find the Southern Cross to use 'the pointers' and the star Achernar.

If you'd like to see a southern equivalent of Polaris, you'll have to wait a very long time. Earth undergoes a continuous change in the orientation of its rotational axis, known as axial precession. A consequence is the pole star changing due to the change in axial orientation. One cycle of precession is about 26,000 years, and in tens of thousands of years Sirius, the 'Dog Star', will be placed close to the south celestial pole. Astronomers certainly won't have a hard time locating such a bright south star.



Natasha Lund, Kielder Observatory, Northumberland

Right: The Southern Cross is the best way to locate the south celestial pole



Did you know?

Telescopes can view wavelengths of light invisible to human eyes - combining these can create images of nebulae showing a rainbow of colour

ASTROPHYSICS

How does a cloud of gas and dust become a star?

Our galaxy, the Milky Way, is filled with interstellar gas peppered with dust, known together as the interstellar medium. This very low-density material churns with turbulent motion between stars, and most of it can remain in this free-moving form for millions or even billions of years. Where pockets of gas become compressed, sometimes through the pressure from a nearby supernova explosion, the density can rise to the point where the inward gravitational pull of the gas on itself is a stronger influence than the dispersing tendency of turbulence. This interstellar cloud can therefore be gravitationally bound, at least for a while.

Through an interplay of the motions within the interstellar cloud, internal gravitational pull and magnetic fields, the cloud can collapse into unstable, long filaments stretching between dense 'hubs' - cloud cores that can further collapse into clusters of dense cores. If a core has enough mass in a small enough volume, the gravitational pull can condense the gas into a hot, spherical 'protostar'.

Material from the surrounding cloud will continue to accrete onto this protostar via an intermediate passage through a circumstellar disc. Eventually enough mass and pressure accumulate to ignite the process of fusion in the central region, creating a fully born star. Stars much more massive than our Sun emit powerful photons that can ionise the remaining gas surrounding the stellar nursery. This brightly coloured gas comprises the colourful nebulae that we now know are not only beautiful, but also signposts of active star formation.



Jennifer Wiseman, senior project scientist for the Hubble Space Telescope

Above: Newly formed stars illuminate surrounding gas and dust to create nebulae

© NASA/ESA

POSSIBLE EARTHLIKE PLANET IN A DEAD STAR'S HABITABLE ZONE

A regular pattern of debris suggests some kind of planetary 'shepherd' in the region

Reported by Elizabeth Howell

Planetary debris, including some objects the size of moons, may hint at a rocky exoplanet within the habitable zone of a stellar zombie. The star in question is a white dwarf called WD 1054-226, a cooling remnant of a star that exhausted all the fuel at its core. If an exoplanet is confirmed in the system, it would be a breakthrough for white dwarf science. Only one other planet has been discovered to date orbiting a white dwarf. That planet, however, is a gas giant - a planet similar to Jupiter - and is not near the habitable zone, usually defined as where liquid water may exist on the surface of a rocky planet.

"The possibility of a major planet in the habitable zone is exciting and also unexpected - we were not looking for this," said lead researcher Jay Farihi, an astrophysicist at University College London. But Farihi cautioned that confirming the planet's existence with current technology won't be straightforward. "Confirmation may come by comparing computer models with further observations of the star and orbiting debris," he said.

WD 1054-226, only 117 light years away from Earth, is close enough to be observed directly by numerous telescopes. The researchers realised a planet might be orbiting the white dwarf from pronounced dips in light detected by the European Southern Observatory's New Technology Telescope at La Silla Observatory in Chile. Additional observations with NASA's Transiting Exoplanet Survey Satellite (TESS), a planet-hunting space telescope, shed more light on why these brightness changes may be



occurring. WD 1054-226's dips in luminosity match with 65 evenly spaced planetary debris clouds that go around the star every 25 hours, the data suggests. The regular distribution of the debris in space suggests a terrestrial planet similar in size to Earth might be keeping everything in place.

White dwarfs provide a bit of a preview of what will happen in our own Solar System when the Sun runs out of hydrogen in about 5 billion years. Before collapsing into underwhelming white dwarfs, stars go through the so-called red giant phase, expanding and burning the planets closest to them. When the Sun turns into a red giant, life on Earth will no longer be possible. The habitable zone will move towards the outer Solar System before shrinking again to include only the closest surroundings of the cooling white dwarf. The theoretical planet at WD 1054-226 is well within the white dwarf's habitable region. It orbits at a distance of 2.5 million kilometres (1.6 million miles) from the parent star, about 28 times closer than Mercury is to the Sun.

More intriguingly, all of the debris and the possible planet must have formed or somehow arrived in the area after the red giant collapsed into the white dwarf. That's because the material is so close that it would have been devoured by the red giant. "It's expected that this orbit around the white dwarf was swept clear during the giant star phase of its life, and thus any planet that can potentially host water, and hence life, would be a recent development," researchers added. "The area would be habitable for at least 2 billion years, including at least a billion years into the future."

THE STELLAR AFTERLIFE

Follow the life cycle of a Sun-like star

All stars begin life as protostars. But how their lives end depends mainly on their mass. For stars below or equal to eight times the mass of our Sun, stellar life can be pretty sedate in comparison with the lives of larger stars, which often explode in catastrophic explosions known as supernovae. Take a relatively tranquil tour of stellar life through to stellar death.

1

1 A PROTOSTAR IS BORN

Stars begin their lives in clouds of gas and dust that have been drawn together by gravity. Their birthplace is known as a giant molecular cloud. When sections of these clouds collapse, a hot, young protostar bursts into existence.

2

2 MAKE OR BREAK

Provided the protostar has at least around 0.08 times the Sun's mass, the collapsing gas and dust burns hotter and hotter. Temperatures get so high that hydrogen is able to fuse into helium. If there's not enough mass, the star fails and becomes a brown dwarf.

3 A BALANCING ACT

The star is switched on and powered by hydrogen fusion. It's industrious, happily burning hydrogen into helium as pressure forces its way outwards. Meanwhile, gravity pushes inwards towards the core. The two forces are balanced and the star is stable.

3

4 THE MAIN SEQUENCE

Just which evolutionary path a main sequence star decides to take depends on its mass. Stars eight times the mass of the Sun or more will explode in violent supernovae, leaving a neutron star or black hole in their wake. Stars that are smaller will take the easier and more sedate route.

4

5

5 MAIN-SEQUENCE FUEL

The mass of a star dictates how long it'll last at the main sequence. You may think the larger a star is, the longer it will last in its current state, but smaller stars take longer to burn up their fuel.

6

6 THE RED GIANT

When a main sequence star has used up all its hydrogen, it begins to swell into a red giant. The star's core switches to helium fusion, pushing out an envelope that's hundreds of times larger than the Sun's radius and glowing with a reddish-orange hue.

7

7 SHEDDING LAYERS

The red giant is ready to push off its outer layers into a ring, forming a beautiful shell of diffuse gas known as a planetary nebula. The core, on the other hand, has collapsed in on itself.

8 CORE SUBJECT

This core is known as a white dwarf, which is extremely dense. While collapsing, its electrons have been smashed together, forming what's known as degenerate matter. This means that a more massive white dwarf has a smaller radius in comparison with its less massive counterpart. White dwarfs aren't able to exceed more than 1.4 times the mass of the Sun.

8

12 ASTRONOMY TUTORIALS TO MASTER

For the very best views of the night sky

Written by Stuart Atkinson and Nigel Watson



GET ANDROMEDA IN YOUR SIGHTS

Make sure you're equipped for the very best views of our nearest spiral, also known as Messier 31

You'll need: ✓ A dark observing site ✓ Our finder charts
✓ A pair of binoculars (optional) ✓ A small telescope (optional)



1 GET DARK ADAPTED

It's important to let your eyes adapt properly. Messier 31's light is spread over a wide area and any light pollution or moonlight will hide it from view.



2 FIND CASSIOPEIA

First find Cassiopeia, a W-shaped constellation high in the Northern Hemisphere sky. Then locate the upside-down 'Y' of Perseus directly by it.



3 USE STAR HOPPING

Starting at Mirfak, the central star in Perseus, slowly 'star hop' two stars along to the right to Mirach in Andromeda.



4 SEEK A SMUDGE

Look for an elongated smudge of light a short distance from Mirach. This is Messier 31. Use averted vision if you don't see it right away.



5 USE BINOCULARS

Use binoculars if you can't see Messier 31 with just your eyes. You will see it as a distinct oval-shaped blur that's grey-white in colour.



6 UPGRADE TO A SMALL TELESCOPE

Through a small telescope Messier 31 will look much brighter. You might even see one or both of its small satellite galaxies, Messier 32 and Messier 110.

MAKE THE MOST OF EARTHSHINE

Combine your images to get the crescent Moon and our planet's glow in one image

You'll need: ✓ DSLR camera ✓ Zoom or telephoto lens ✓ Small telescope ✓ Tripod



1 DECIDE ON YOUR SHOT TYPE

Set up your equipment and choose either a wide-angle shot or a more close-up image using a zoom or telephoto lens or even a small telescope.



2 LOCATE THE MOON UNDER MAGNIFICATION

It sounds simple, but finding the Moon can be tricky under magnification. Once you've found it, centre it in the viewscreen of your camera and snap away.



3 FOCUS ON THE EARTHSHINE

Once you're happy with your shots of the crescent Moon, shift your focus to the Earthshine. Don't wait too long to take the next shot though.



4 PROCESS YOUR IMAGES

Using Photoshop or similar photo-editing software, combine the two images to get a perfectly exposed picture of 'the old Moon in the new Moon's arms'.

BE PREPARED FOR AN ISS PASS

There's plenty of software to help you look for the International Space Station

You'll need: ✓ Clear sky
✓ Binoculars (optional)
✓ Website or app with visibility information



1 FIND A SUITABLE WEBSITE TO CHECK TIMINGS

Use a website or an app on your tablet or phone to find out when the ISS will be visible from where you are. Spotthestation.nasa.gov is a good starting point.



2 GET A WIDE-OPEN VIEW

If you can travel, go and watch the skies for the ISS from somewhere with a wide-open view of the sky, with a clear view from west to east. But anywhere with clear skies will do.



3 FACE THE RIGHT DIRECTION

Face roughly west about five to ten minutes before the pass is due to begin, waiting patiently for a 'star' to appear climbing up from the horizon.



4 TRACK THE STATION

Follow the ISS moving across the sky for as long as you can, watching how it fades as it falls towards the east. Wave at the astronauts on board if you like!

OBSERVE JUPITER'S ANTICYCLONE

The gas planet's Great Red Spot never fails to disappoint

You'll need: ✓ A telescope ✓ A selection of eyepieces
✓ Coloured filters ✓ A notebook or drawing pad



1 USE A TRACKING MOTOR

Set up your telescope with a tracking motor if you have one. It's essential your instrument has been assembled on a level surface to avoid wobbling.



2 USE A LOW-POWER EYEPIECE

Eyepieces that combine with your telescope for a low power should be used first. Switch to a higher magnification if the observing conditions are fair.



3 ATTACH A COLOURED FILTER

Experiment by using various coloured filters. Start with a light yellow filter to enhance the contrast of Jupiter's atmosphere.



4 USE AN EPHEMERIS

It's good to know when certain features will be on view, so use information on the internet to find out the best viewing times.



5 FIND THE GREAT RED SPOT

This particular storm is not always visible, but when it is, take some time to make a note of its colour and shape. It's spectacular to view.



6 TAKE NOTES OR SKETCH JUPITER

It's great to keep a record of what you see. Draw a circle on some paper and fill it in using coloured pencils to record Jupiter exactly as you see it.

IMPROVE YOUR METEOR PICTURES

Here's how to get some great time-lapse photographs of 'falling stars' during a shower

You'll need: ✓ DSLR camera ✓ Wide-angle lens ✓ Sturdy tripod
✓ Intervalometer ✓ Spare memory card



1 GET YOUR DIGITAL CAMERA READY

Set up your DSLR camera to an exposure of 20 to 25 seconds and an ISO setting of 800 to 1,600, depending on conditions.



2 SET UP YOUR TRIPOD

After unfolding your tripod, make sure that everything is locked in position and sturdy. You don't want anything 'sagging' mid-shot.



3 ADJUST THE FOCUS

Check the focus of your camera. A sharp focus will be the difference between registering faint meteors or missing them altogether.



4 SET UP THE INTERVALOMETER

Set up your shutter release for exposure lengths of around 20 to 25 seconds and for continuous shooting. This will control the camera.



5 CHECK THE MEMORY CARD

Keep an eye on the camera's memory card. It can fill up quite quickly when shooting in RAW, so make sure you have a spare to hand for when it's full.



6 PROCESS THE SHOTS

Go through the frames you have taken, ensuring that you save the ones with the most meteors. Use photo-editing software to adjust the contrast.

CAPTURE THE MILKY WAY GALAXY

Take plenty of photos to ensure a great final result

You'll need: ✓ DSLR camera ✓ A dark-sky site
✓ Wide-angle lens ✓ Tripod ✓ A cable release ✓ Photo-processing software



1 POSITION YOUR CAMERA

Pointing it towards your chosen area of sky, turn your camera onto its side to give a portrait image. Focus sharply on either a bright star or a distant light on the horizon.



2 ALTER THE EXPOSURE TIME

Press the cable release to take your first image. If your target isn't clear, try increasing the ISO or exposure time until it looks more obvious.



3 SHOOT A SERIES

When you have some images you are happy with, take a series of overlapping photos panning upwards to turn into a mosaic later when you are processing your images.



4 ALTER THE CONTRAST

Use processing software to increase the contrast and improve the appearance of your images, but don't go too far and make them garish or unrealistic.

SHOOT SUMMER'S NOCTILUCENT CLOUDS

Use these tips to have a better chance at spotting this phenomena

You'll need: ✓ No obstructions on the horizon ✓ A pair of binoculars ✓ Tripod



1 KNOW WHAT TO LOOK FOR

Noctilucent clouds can be different colours. Look out for simple arcs or wisps of gold or more complex swirls and whirls of electric blue, often silhouetting clouds lower in the atmosphere.



2 BE PREPARED FOR BRIGHTENING AND FADING

If a display dies down, don't give up – it might brighten again. Many of the largest displays fade away part way through before coming back.



3 UPGRADE TO BINOCULARS

Binoculars will show you beautiful detail inside noctilucent clouds – whirls and swirls, cross-hatch patterns and long, sinuous lines of smoky cloud, shining in shades of violet and electric blue.



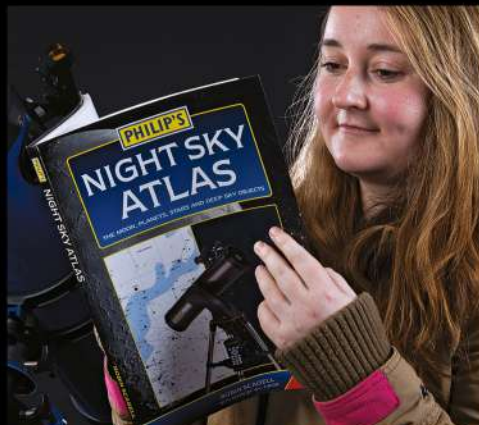
4 TRY TAKING PHOTOS

A DSLR on a tripod can snap great images of noctilucent clouds. Set a high ISO and take exposures of several seconds. If fine details are washed out use shorter exposures.

OBSERVE DEEP-SKY TARGETS

There's no point looking for an object your instrument can't see – know its observing capabilities before you set out

You'll need: ✓ Telescope ✓ Red torch ✓ Detailed star chart ✓ Filters (optional)



1 SELECT YOUR TARGETS WISELY

Choose a few objects fairly high in the sky which are within the grasp of your telescope. You should use a night sky-guide to plan your evening.



2 GET DARK-ADAPTED EYES

Allow your eyes to get accustomed to the dark – it can take up to half an hour for your pupils to respond to low light. Use a red torch for reading.



3 CHOOSE THE RIGHT EYEPIECE

Carefully select an eyepiece that won't push your telescope beyond its observing capabilities, otherwise you'll get a blurred image.



4 MAKE THE MOST OF AVERTED VISION

If you can't see the object, look away from the centre of the field of view and see if you can detect it using your peripheral vision.



5 BE SURE TO BREATHE

A couple of deep breaths can help oxygenate your brain, which in turn helps your visual acuity, often helping with fainter targets.



6 YOU MIGHT NEED TO USE FILTERS

If you still can't see your target, try using a suitable filter or try to observe it another night, as atmospheric transparency might be the issue.

STAR-HOP AROUND THE NIGHT SKY

Navigating takes practice. Follow our guide to learn the basics of finding your way around the constellations and deep-sky targets

You'll need: ✓ Star chart ✓ Red torch ✓ Binoculars ✓ Small telescope



1 CHOOSE AN OBJECT

Start with an object that is bright enough to be easily seen. It's best to go for a target that can also be seen with the naked eye or binoculars.



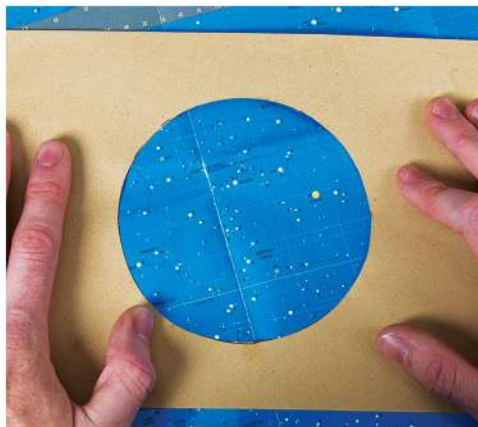
2 KNOW YOUR FIELD OF VIEW

A circle that's the same diameter as your instrument's aperture is helpful, ensuring you see the same field on your chart.



3 START FROM A BRIGHT STAR

Start your hopping from a reasonably bright star in the constellation in which the object you want to find resides – you can restart easily if you get lost.



4 DECIDE ON THE STEPS

Use your map and look through your instrument to gain familiarity with the objects that you'll be using to get to your target.



5 CHANGE YOUR FIELD

Use a star or star pattern on the 'outside of the circle' on your map and place it in your field of view. Keep doing this until you reach your chosen object.



6 TAKE YOUR TIME

This means you are less likely to get lost, and you may find interesting things to look at on the way. The more skilled you are, the easier it gets.

TAKE PLANET IMAGES WITH YOUR PHONE

Being prepared and following a methodical approach is key to imaging the Solar System

You'll need:

✓ Smartphone ✓ Phone bracket ✓ A tracking mount ✓ Telescope



1 DECIDE ON A PLANET TO IMAGE

Find and centre the planet you wish to image through your telescope eyepiece. Venus and Mars are good targets for capturing detail.



2 MAKE THE MOST OF YOUR TELESCOPE'S MOTOR

Ensure that your telescope mount's drive system is on and operating. Motors are useful for tracking the planets through the course of the night.



3 MAKE SURE YOU HAVE A GOOD VIEW

Check that you have a decent image of the planet on your phone's screen. Try to get it in focus as much as you can using your telescope's focuser.



4 ENSURE YOUR CHOSEN PLANET IS CENTRED

If your target is in the centre of the field of view, it's likely to align in your camera's view.

GET FLAWLESS STAR TRAIL IMAGES

It's all about a bit of mix and match when shooting stars as the Earth turns

You'll need: ✓ DSLR camera ✓ Telescope camera adaptor
✓ Tracking mount ✓ A small telescope



1 GET A STURDY SET-UP

A sturdy tripod will keep it as steady as possible. Be sure to carefully check that nothing on your tripod will move or slip during your long exposures.



2 TWEAK YOUR SETTINGS

Open a 50mm lens to its widest aperture, ideally under f/3. Set your camera to Manual, ISO to 400 and exposure time to 30 seconds. Set a time delay.



3 CHOOSE A FAMILIAR TARGET

Direct your camera at a constellation that you know and then focus it sharply on either a bright star or a distant light on the horizon.



4 TAKE YOUR FIRST SHOT

Press the cable release to take your first image. You will see that the stars will have trailed. If you find the image is too dark, increase the ISO.



5 GET CREATIVE

To be more artistic, point your camera in a direction in which there are stars or a bright planet shining above features in your local landscape.



6 COMBINE YOUR SHOTS

You can use software to combine your star trail images to make one very striking image showing very long star trails with the foreground in focus.

SNAP THE STUNNING PHASES OF VENUS

How you can achieve superb shots of our neighbour

You'll need: ✓ DSLR camera ✓ Telescope camera adaptor
✓ Small telescope ✓ Tracking mount



1 AIM YOUR TELESCOPE

Point the camera and the telescope towards Venus. Make sure you cap off the finderscope if the planet is very close to the Sun and be careful not to cause any damage to your eyes.



2 TURN ON THE DRIVE

Switch on the drive and wait for it to settle before you start taking your series of images. Make sure that your equipment is well set up, sturdy and, most importantly, still.



3 SET THE EXPOSURE TIME

Try to keep the exposure times for your shots as short as possible as Venus is very bright in the sky. You may need to increase the ISO value, but don't overdo it.



4 PROCESS YOUR IMAGES

You may have to adjust the contrast of your images to allow for the lighter sky during thin crescents. Process your images using photo-editing software.

WORLD OF KNOWLEDGE



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BEST ACCESSORIES FOR YOUR TELESCOPE

FROM BEATING LIGHT POLLUTION TO SUPERB VISUALS OF THE PLANETS AND GALAXIES, CELESTRON HAS EVERYTHING YOU NEED FOR SUPERB VIEWS OF THE NIGHT SKY



ULTIMA EDGE

These flat-field eyepieces are designed to provide an ultra-sharp, ultra-clear, crisp image from the centre all the way to the edge of the field of view. The Ultima Edge eyepiece features fully multi-coated optics and a nine-element lens design, maximising light transmission. The Ultima Edge range - which includes 10mm, 15mm, 18mm, 24mm and 30mm for low and high-powered magnification - include a generous field of view, perfect for viewing planets, stars, deep-sky targets and the Moon's surface. The 1.25" or 2" mounting barrel is internally threaded to accept standard 1.25" or 2" filters and adapters. It is compatible with 1.25" or 2" star diagonals and focusers. On the exterior of the eyepiece, you will find a uniquely designed moulded rubber grip ring for non-slip handling. Viewing through the Ultima Edge eyepiece is comfortable for both eyeglass wearers and non-eyeglass wearers alike, thanks to the fold-down rubber eyecups and long eye relief.

E-LUX

Get more light to your eye and enjoy the low-power, wide-field views of Celestron's E-lux 2" eyepieces, offered in focal lengths of 26mm, 32mm and 40mm. Designed to be used with any telescope with a 2" focuser, the Celestron E-lux eyepiece is a three-element, fully multi-coated Kellner design that offers a great magnification and field of view for viewing planets, stars, deep-sky targets and the Moon's surface. The E-Lux range has a main housing that is machined from high-grade aluminium with a black anodised outer surface. The internal surface of the mounting barrel has been machined with light dispersion threads that are painted matte black to cut down on internal reflections for a clear viewing experience.

OMNI

Celestron Omni series eyepieces, which include focal lengths of 4mm, 6mm, 9mm, 12mm, 15mm, 32mm, 40mm and 56mm, offer a 50-degree apparent field of view, perfect for the Moon, planets and a plethora of deep-sky objects. The premium four-element optical set is finished with multiple layers of high-transmission coatings for clear, sharp images. The edges of the optics are blackened for increased contrast. The Omni eyepiece body is made of aluminium. A two-step anodising process results in a beautiful matte finish that resists reflections and glare. Each eyepiece in the Omni Series includes a black rubber eyecup. It can be left up or folded down for better observations while wearing eyeglasses. The longer barrelled 15mm, 32mm and 40mm eyepieces include a rubberised grip for non-slip handling during observing sessions. The insert barrel is threaded to accept 1.25" or 2" filters.

"PERFECT FOR THE MOON, THE PLANETS AND A PLETHORA OF DEEP-SKY OBJECTS"



X-CEL LX

Celestron X-Cel LX series eyepieces offer a 60-degree apparent field of view, perfect for the Moon, the planets and a plethora of deep-sky objects. The premium six-element optical set is finished with multiple layers of high-transmission coatings for clear, sharp images. The edges of the optics are blackened for increased contrast. All seven X-Cel LX eyepieces - 2.3mm, 5mm, 7mm, 9mm, 12mm, 18mm and 25mm - sport 16mm of comfortable eye relief and are parfocal, which means you can switch out eyepieces within the series during observing sessions and little or no additional focusing will be required. Premium 3x and 2x Barlow lenses are included in the range. The X-Cel LX eyepiece body is made of black-anodised aluminium. The pop-up eyecups make it easy to adjust the height for different users. Turn them in one direction to extend the length and the other direction to provide a flat surface, preferable to most eyeglass wearers.

LUMINOS

The Luminos series offer a wide 82-degree field of view in both high-power and low-power models, allowing you to make the most of your telescope whether you own a short, fast refractor or a Celestron EdgeHD telescope. The optical set consists of six or seven elements, depending on the model, and is fully multi-coated for crisp, sharp views. All six Luminos eyepieces - 7mm, 10mm, 15mm, 19mm, 23mm and 31mm - are parfocal, which means you can switch out eyepieces during observing sessions with little or no additional focusing required. A 2.5x Barlow lens is also included in the series. The Luminos eyepiece body is made of polished and anodised aluminium. A rubber grip runs around the equator of the eyepiece, giving you a secure grip and an easy method for raising and lowering the retractable eyecup. Simply twist the rubber grip to adjust the height of the eyecup. The insert barrel, either 1.25" or 2", is threaded to accept filters.



EYEPIECE AND FILTER KIT

The Celestron 1.25" Eyepiece and Filter Kit is a great way to expand the functionality and enjoyment of your telescope. A sturdy metal carry case is included. All five Plössl eyepieces can be used in any telescope with a 1.25" focuser. Each eyepiece - 32mm, 17mm, 13mm, 8mm and 6mm - features a four-element design with a 52-degree apparent field of view. The optics are fully multi-coated to improve light transmission and protect the optics. The included 2x Barlow doubles the magnification of any 1.25" eyepiece. Since this kit includes five eyepieces, you will be able to use them with and without the Barlow, giving you a total of ten magnification options in all.

The coloured filters - #80A Blue, #58 Green, #56 Light Green, #25 Red, #21 Orange, #12 Yellow and Moon - can be used to bring out certain details on a planet's surface or cloud structure, while the Moon filter is one of the first accessories most new amateur astronomers buy - and for good reason! It helps block out a portion of the light the Moon sends into your eyepiece so that you can see details better. You can also try this filter on Venus; it blocks enough glare so you can observe the planet's phases more easily.



WHAT'S IN THE SKY?

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"TOTAL LUNAR ECLIPSE VISIBLE FROM AFRICA, THE AMERICAS, EUROPE AND FRENCH POLYNESIA"

RED-LIGHT FRIENDLY

In order to preserve your night vision, you should read our observing guide under red light

22 APR



The Lyrids reach their peak of 18 meteors per hour

24 APR



The Pinwheel Galaxy (Messier 101) is well placed for observation in Ursa Major

24 APR



Conjunction between the Moon and Saturn in Capricornus

26 APR



The Moon and Mars make a close approach, passing within 3°34' of each other in Aquarius

27 APR



Conjunction between the Moon and Venus in Aquarius

27 APR



Conjunction between the Moon and Jupiter in Pisces and Aquarius

29 APR



Mercury is at its greatest elongation in the evening sky

30 APR



Conjunction between Venus and Jupiter in Pisces

30 APR



Partial solar eclipse visible from South America and Antarctica

9 MAY



The Eta Lyrids reach their peak of three meteors per hour



13 MAY



Globular cluster Messier 5 is well placed for observation in Serpens Caput

Source: Wikipedia Commons ©Adam Block/Mount Lemmon SkyCenter/University of Arizona

JARGON BUSTER

CONJUNCTION

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

DECLINATION (DEC)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

OPPOSITION

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

RIGHT ASCENSION (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

MAGNITUDE

An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

GREATEST ELONGATION

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

25
APR



The Moon and Saturn make a close approach, within $4^{\circ}15'$ of each other in Capricornus

25
APR



Mercury reaches half phase (dichotomy) in the evening sky

25
APR



Conjunction between the Moon and Mars in Aquarius

27
APR



The Moon and Jupiter pass within $3^{\circ}15'$ of each other in Pisces and Aquarius

28
APR



Mercury is at its highest altitude in the evening sky

29
APR



Asteroid 10 Hygiea reaches opposition in Virgo, glowing at magnitude +9.3

30
APR



Venus and Jupiter make a close approach, within $13.8'$ of each other in Pisces

5
MAY



The Eta Aquariids reach their peak of 55 meteors per hour



©ESO

16
MAY



Total lunar eclipse visible from Africa, the Americas, Europe and French Polynesia

18
MAY



Conjunction between Mars and Neptune in Aquarius and Pisces

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

STARGAZER

PLANETARIUM

5 MAY 2022

DAYLIGHT

MORNING SKY

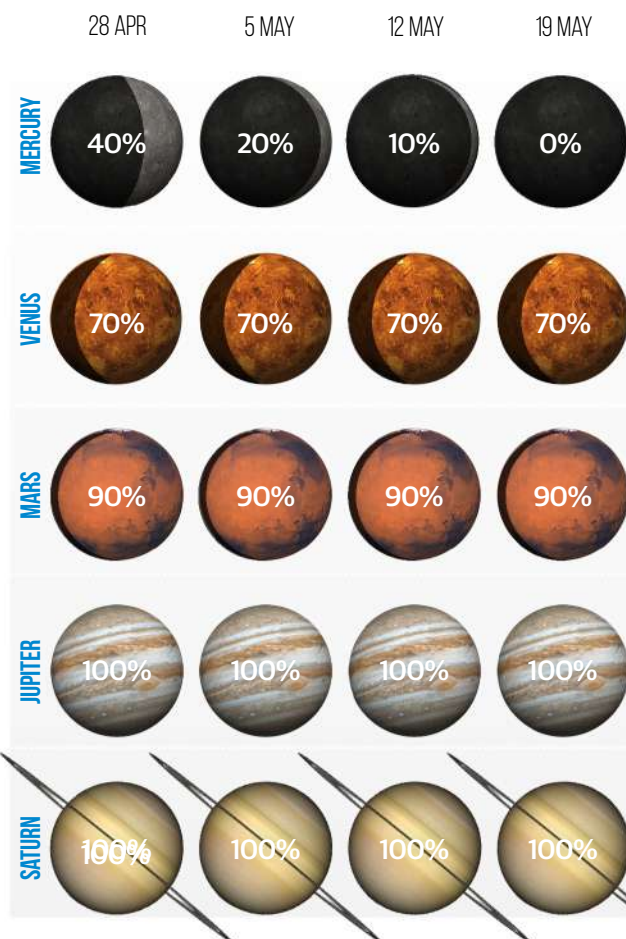
* The Moon does not pass the meridian on 15 May



What's in the sky?



ILLUMINATION PERCENTAGE



PLANET POSITIONS

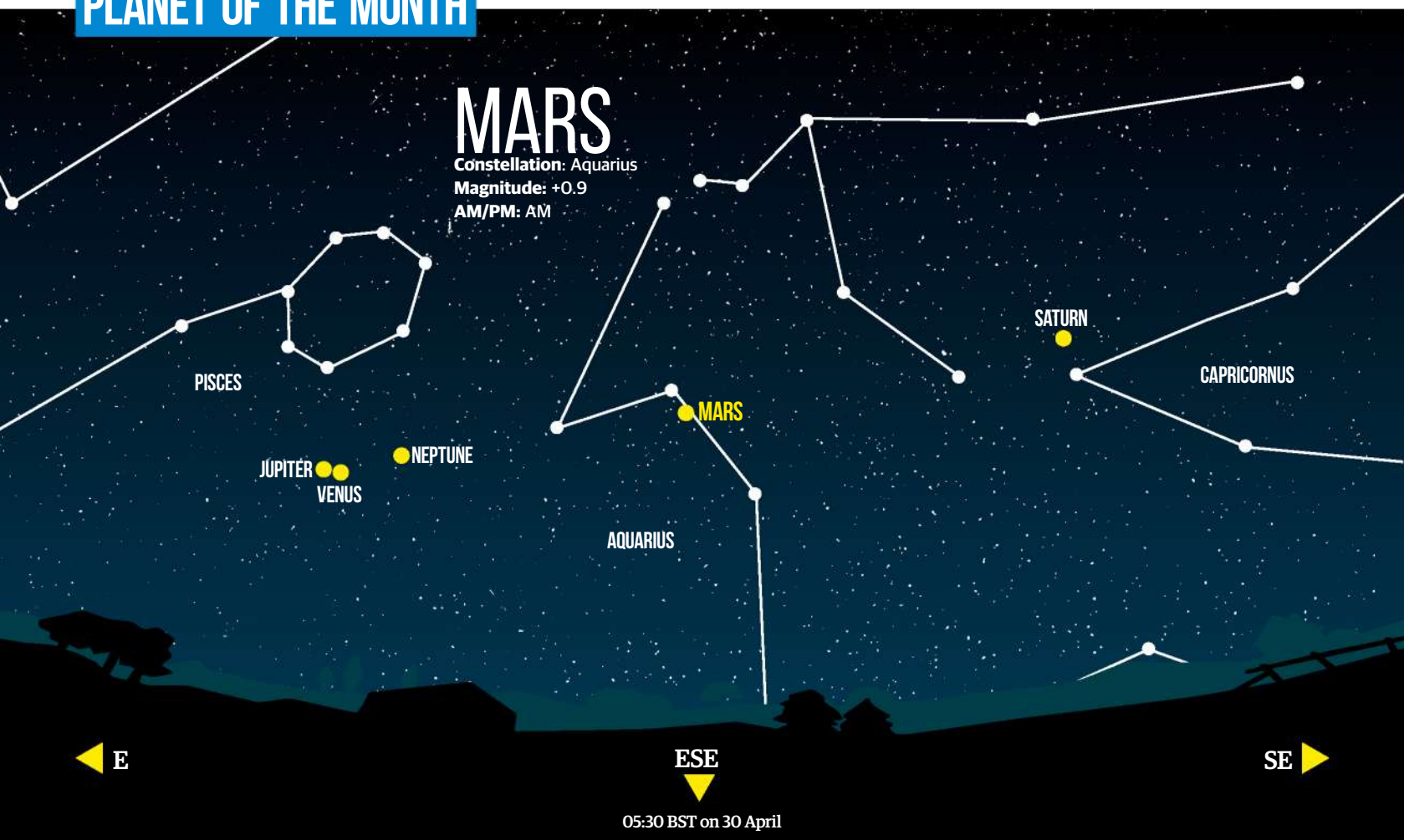
All rise and set times are given in BST

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
21 APR	03h 00m 50s	+19° 13' 28"	Aries	-0.8	06:14	21:55
28 APR	03h 39m 21s	+22° 15' 37"	Taurus	-0.0	06:05	22:22
5 MAY	04h 02m 45s	+23° 15' 51"	Taurus	+1.1	05:53	22:25
12 MAY	04h 08m 48s	+22° 25' 48"	Taurus	+2.9	05:38	21:58
19 MAY	03h 59m 53s	+20° 08' 38"	Taurus	+0.7	05:17	21:06
21 APR	23h 11m 31s	-06° 00' 06"	Aquarius	-4.2	04:40	15:47
28 APR	23h 41m 12s	-03° 17' 21"	Pisces	-4.1	04:29	16:03
5 MAY	00h 10m 58s	-00° 25' 49"	Pisces	-4.1	04:16	16:19
12 MAY	00h 40m 52s	+02° 30' 48"	Cetus	-4.0	04:04	16:36
19 MAY	01h 11m 04s	+05° 28' 58"	Pisces	-4.0	03:51	16:54
21 APR	22h 26m 11s	-11° 19' 42"	Aquarius	+0.9	04:23	14:34
28 APR	22h 46m 16s	-09° 25' 38"	Aquarius	+0.9	04:05	14:41
5 MAY	23h 06m 06s	-07° 27' 59"	Aquarius	+0.9	03:48	14:39
12 MAY	23h 25m 43s	-05° 27' 49"	Aquarius	+0.8	03:29	14:41
19 MAY	23h 45m 08s	-03° 26' 06"	Aquarius	+0.8	03:11	14:43
21 APR	23h 45m 17s	-02° 43' 55"	Pisces	-2.1	04:58	16:37
28 APR	23h 50m 51s	-02° 08' 52"	Pisces	-2.1	04:33	16:18
5 MAY	23h 56m 13s	-01° 35' 13"	Pisces	-2.1	04:08	15:59
12 MAY	00h 01m 21s	-01° 03' 12"	Pisces	-2.2	03:43	15:39
19 MAY	00h 06m 12s	-00° 33' 00"	Pisces	-2.2	03:17	15:19
21 APR	21h 44m 03s	-14° 40' 27"	Capricornus	+0.9	03:59	13:34
28 APR	21h 45m 49s	-14° 32' 39"	Capricornus	+0.9	03:33	13:09
5 MAY	21h 47m 19s	-14° 26' 12"	Capricornus	+0.9	03:06	12:43
12 MAY	21h 48m 33s	-14° 21' 14"	Capricornus	+0.8	02:40	12:17
19 MAY	21h 49m 28s	-14° 17' 47"	Capricornus	+0.8	02:13	11:51

THIS MONTH'S PLANETS

Mars shines in the dawn sky alongside the majority of the Solar System's outer gas planets

PLANET OF THE MONTH



Mars will be an important member of the parade of planets that will be stretched out across the predawn sky from the east to the southeast. If Mars was shining high in a dark sky at +0.9 it would be a striking sight, an obvious orange-red 'star' to the naked eye. However, during April and May Mars will be shining low in a sky bright with the slow but relentless approach of sunrise, so it will not be as easy to see. In fact, if your sky is misty or hazy you might even struggle to spot it without binoculars.

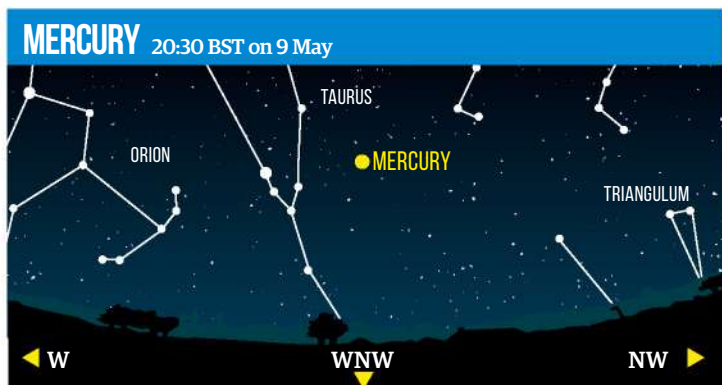
At the start of our observing period the planets on either side - Venus to its left and Saturn to its right - will both be much brighter and more obvious, so if you look between them you should

be able to pin down the famous Red Planet. But the planets in the parade will be spending the month ahead shifting their positions and order, and by the end of our observing period Mars will have moved away from Saturn and will be shining just six degrees away from Jupiter, which will itself have swapped positions in the line with Venus. By then Mars will be rising just an hour before the Sun.

Interestingly, during the second week of May Mars will appear very close in the sky to a comet. Unfortunately, Comet 22P/Kopff will be much fainter than Mars, shining - if that's the right word - at around tenth magnitude, making it far too faint to see without binoculars or a

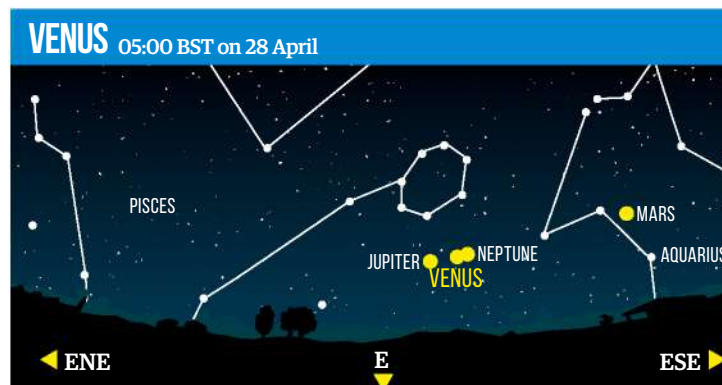
telescope. And as the comet will be so low in a rapidly brightening sky, it'll be very hard to see, but views are possible if you have patience and good skies.

Meanwhile - barring any accidents or mechanical failures - two nuclear-powered robot geologists are currently trundling around Mars, studying not just its geology but its weather and climate. By the time you read this, Perseverance, which landed on Mars in February 2021, should have reached the front edge of an ancient, preserved river delta and will have begun using its onboard arsenal of cameras, detectors and scientific instruments to look for signs of past life in the delta's outcrops and layers.



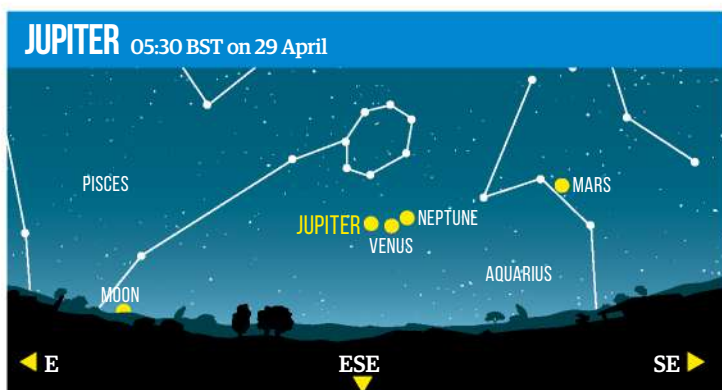
Constellation: Aries **Magnitude:** -0.6 **AM/PM:** PM

Mercury will be an evening star at the start of our observing period, visible as a copper-hued star low in the western sky after sunset, close to the famous Pleiades star cluster. With a magnitude of -0.6 it should be visible to your naked eye in the twilight. It can be hard to spot initially, so scan the western sky with binoculars after sunset until it pops into view.



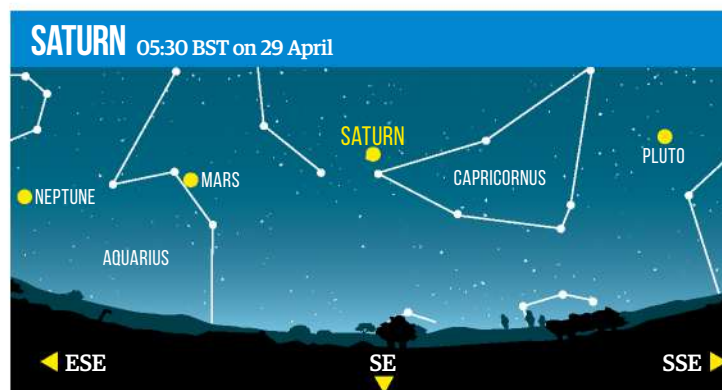
Constellation: Aquarius **Magnitude:** -4.2 **AM/PM:** AM

Shining at magnitude -4.2, Venus is a naked-eye morning star this month. Before sunrise on 29 April Venus will shine one-and-a-half degrees to Jupiter's right. The following morning that gap will have shrunk to less than half a degree, or roughly the width of the full Moon, and by 2 May the two worlds will have moved two degrees apart.



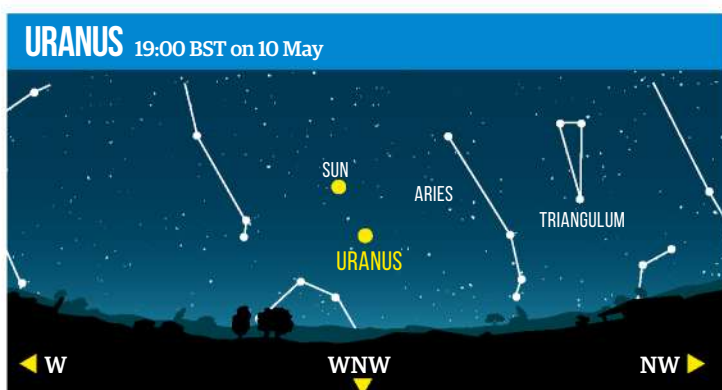
Constellation: Pisces **Magnitude:** -2.1 **AM/PM:** AM

The second-brightest member of the planet parade, Jupiter will start our observing period on the eastern end of the chain of worlds. In late April it will rise only 40 minutes before the Sun, so its brightness will be greatly diminished by the bright morning twilight. As the month passes Jupiter will move away from the Sun and its visibility will improve.



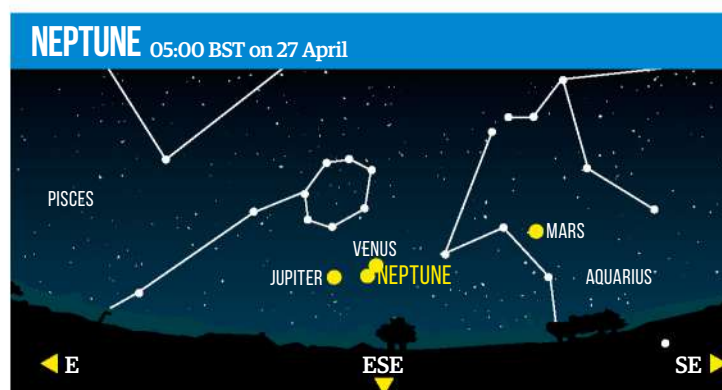
Constellation: Capricornus **Magnitude:** +0.9 **AM/PM:** AM

Saturn will be a yellow-hued morning star easily visible to the naked eye. At the end of April it rises around 90 minutes before the Sun, and by late May it will be rising two hours before sunrise. With a pair of binoculars you'll be able to see Titan, Saturn's largest moon, looking like a tiny star close to it, but if you want to see its famous rings you'll need a telescope.



Constellation: Aries **Magnitude:** +5.9 **AM/PM:** PM

At the end of April Uranus will be an evening object, low in the west after sunset, lurking close to the setting Sun and Mercury, but at magnitude +5.9 this distant green world will be overwhelmed by the bright twilight, setting only an hour after the Sun. As the days pass Uranus will grow closer and closer to the Sun, until it's lost in its glare and then passes behind it.



Constellation: Aquarius **Magnitude:** +7.9 **AM/PM:** AM

Neptune will be by far the faintest member of the planet parade this month, a morning object that will be hard to see - even with help from binoculars or a telescope - because of the brightness of the predawn sky. At the start of our observing period it will be positioned very close to Jupiter, but will appear to be pulling away from that planet and moving closer to Venus.

MOON TOUR

MARE CRISIUM

The lunar sea offers spectacular bright views this month

Despite their name, the prominent lunar features known as 'seas' – 'maria' in Latin – aren't stretches of liquid water. They're vast pools of dark lava that flooded low-lying areas, but mainly impact basins, several billion years ago. These lava flows have long since solidified. It was only in ancient times – long before telescopes were first invented – that these dark patches, so clearly visible with the unaided eye, were speculated to be marine regions. But for more than 400 years we have known that the Moon's seas are decidedly solid areas – no waves lap at their shores and no wind billows across their expanses.

Mare Crisium (the Sea of Crises) is the most 'self-contained' sea on the Moon's nearside. Viewed from above, it's markedly oval in shape; measuring 570 by 450 kilometres (354 by 280 miles), its longest axis is oriented east-west. When viewed from Earth, Mare Crisium's position near the Moon's eastern edge causes its east-west axis to be 'squashed', making it appear longer along its north-south axis. The apparent shape of Mare Crisium and its nearness to the eastern edge of the Moon is a good naked-eye guide to the extent of lunar libration.

Libration, the apparent slight rocking of the Moon from side to side during the month, allows a total of 59 per cent of the Moon's surface to be seen over time, while the remaining 41 per cent of the Moon – the true far side – is always unobservable from Earth. Libration affects the way in which we view lunar features, especially those lying nearer to the Moon's edge, and whenever Mare Crisium is on show, those with a keen naked eye will be able to determine the state of the Moon's libration.

Libration favouring the eastern edge of the Moon will show Mare Crisium to good effect, while a strong libration favouring the Moon's western edge will push Mare Crisium near the Moon's edge, foreshortening it to a considerable extent. During the first half of May, as the Moon waxes in the evening skies, libration greatly favours Mare Crisium, while the remainder of May sees Mare Crisium gradually being pushed ever closer to the Moon's edge.

TOP TIP!

Mare Crisium will make a spectacular sight in early May through any optical instrument. Fully exposed to sunlight, it will appear as a large, flooded crater. A Moon filter will improve contrast, toning down any glare.

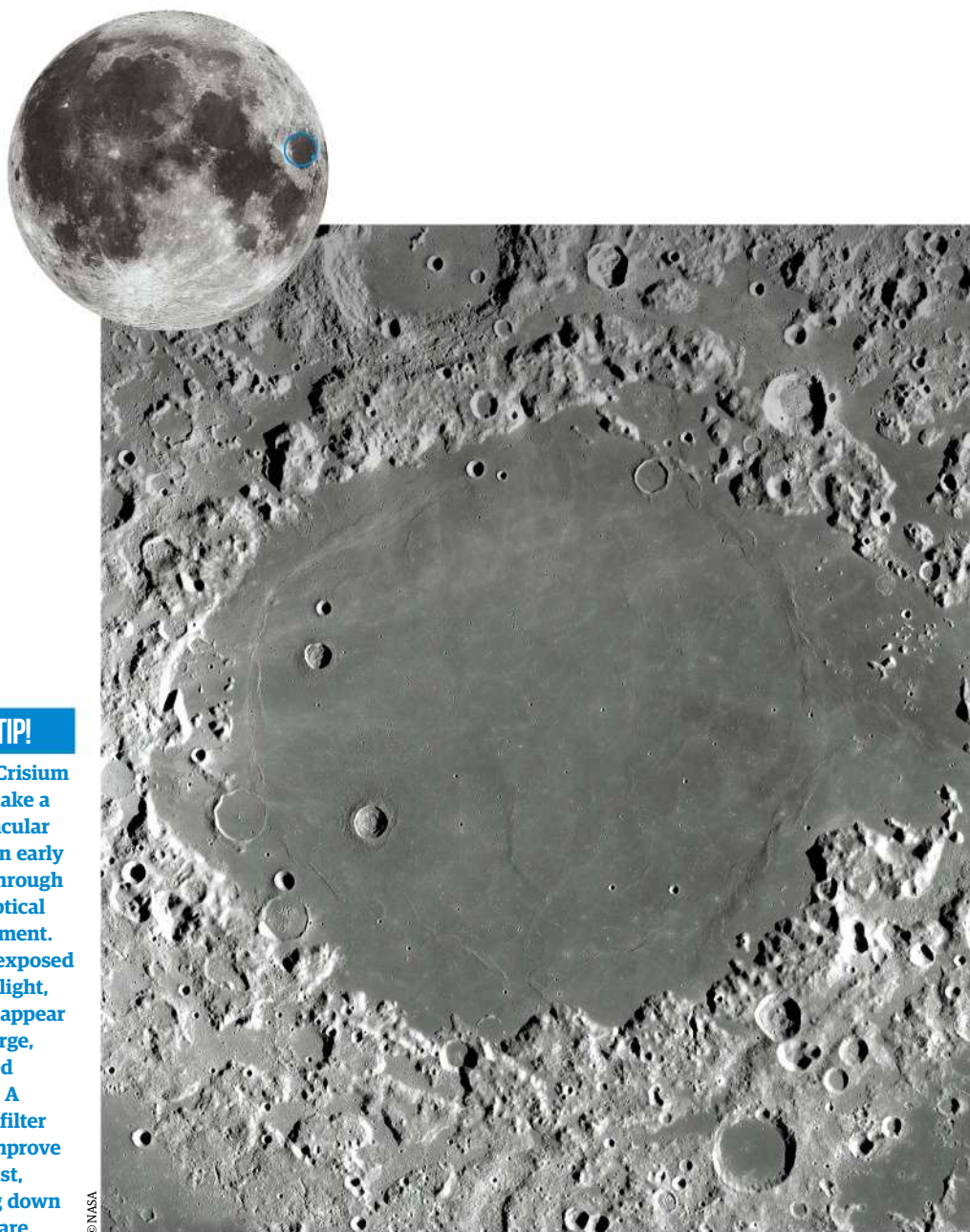
© NASA

The neat, oval-shaped Mare Crisium produces a noticeable 'dent' on the terminator of the young lunar crescent, visible without optical aid to those with keen eyes on the evening of 4 May. Fully exposed to the sunshine a day later, Mare Crisium makes a spectacular sight through any optical instrument, looking like a large flooded crater, which is exactly what it is. Mare Crisium has lofty western mountain borders whose clean-cut cliffs shine brilliantly in the morning light. Under a low illumination, a concentric system of wrinkle ridges comes into view. These ridges average about 50 kilometres (31 miles) from the mare border, forming a disjointed internal ring.

Dorsum Oppel, the most prominent of these wrinkles, links with the flooded crater Yerkes in the west and curves around the northwestern periphery of the mare for 300 kilometres (186 miles), where it is intercepted by half a dozen narrow wrinkles that cross the mare from the northwestern border. In the northeast lies the narrower Dorsa

Tetyaev, at 150 kilometres (93 miles) long, and Dorsa Harker at 200 kilometres (124 miles) long. As the Sun climbs higher, numerous light-coloured rays cross Mare Crisium's mottled surface, notably those from the bright impact crater Proclus just beyond its western border. Several impact craters dot its surface – Picard, Peirce and Greaves can be seen under a midday illumination.

On 17 to 18 May, a few days after full Moon, Mare Crisium's western border casts shadows as its eastern reaches begin to darken with the nearing sunset terminator, the mountains of its eastern border glinting in the setting Sun. A considerable breach exists in the eastern mountain border where the mare lava has flowed into outlying craters and valleys, notably Mare Anguis (the Serpent Sea), one of the smallest lunar maria, which is an irregular, dark patch measuring about 200 kilometres (124 miles) from north to south. A large mountainous headland, Promontorium Agarum, projects into Mare Crisium from its southeastern shore.



NAKED EYE & BINOCULAR TARGETS

Lone stars and globular clusters are among the treats on view in the spring night sky

1 Crater

This constellation is said to represent a cup of water brought to the god Apollo by a crow. Delta Crateris and Alpha Crateris, at magnitudes of +3.56 and +4.07 respectively, are the constellation's two brightest stars, easily detected with 10x50 binoculars.

2 Alphard (Alpha Hydrae)

This star's name means 'the solitary one'. Alphard is aptly named, as it's the only bright star in this region of sky. Hydra (the Water Snake) – the constellation that this magnitude +2.0 star occupies – stretches across the sky. To the naked eye and binoculars, Alphard has a warm, orange colour that's not too showy.

3 Corvus

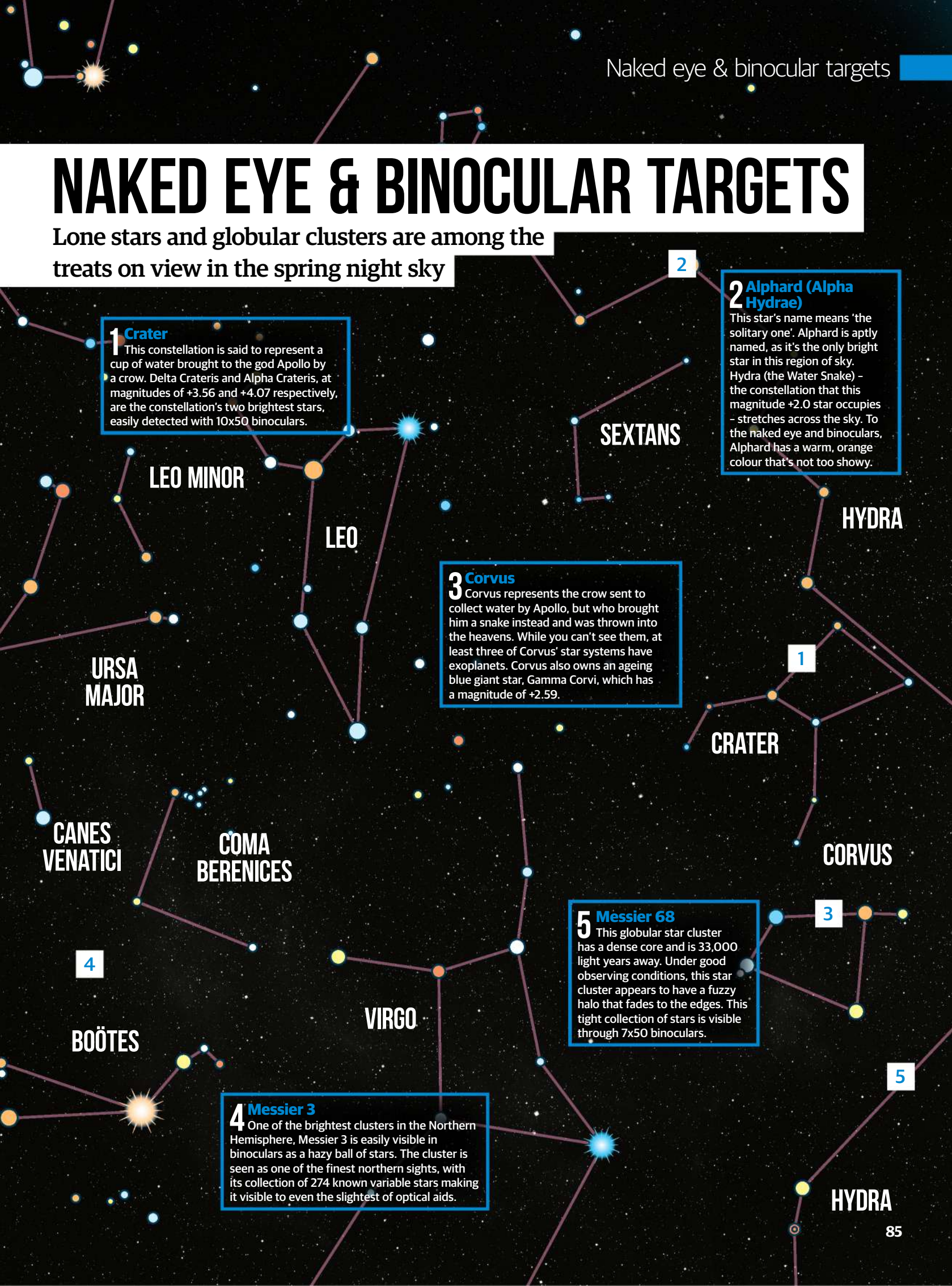
Corvus represents the crow sent to collect water by Apollo, but who brought him a snake instead and was thrown into the heavens. While you can't see them, at least three of Corvus' star systems have exoplanets. Corvus also owns an ageing blue giant star, Gamma Corvi, which has a magnitude of +2.59.

5 Messier 68

This globular star cluster has a dense core and is 33,000 light years away. Under good observing conditions, this star cluster appears to have a fuzzy halo that fades to the edges. This tight collection of stars is visible through 7x50 binoculars.

4 Messier 3

One of the brightest clusters in the Northern Hemisphere, Messier 3 is easily visible in binoculars as a hazy ball of stars. The cluster is seen as one of the finest northern sights, with its collection of 274 known variable stars making it visible to even the slightest of optical aids.



Messier 100

DEEP SKY CHALLENGE

THE REALM OF THE GALAXIES

Evenings reveal a gaggle of galaxies when we look out into deep space in the direction of some of the most well-known constellations

The region of sky around the constellations of Leo, Coma Berenices and Virgo is known as the 'realm of the galaxies', and this is a perfect time of year to go hunting for those faint, fuzzy and very distant objects. Galaxies come in all shapes, sizes and distances, meaning that they can seem larger and brighter or smaller and fainter depending on their individual attributes. They can also come in groups. This can be a line-of-sight effect or it can be the result of gravitational interactions between individual galaxies. Some larger, brighter galaxies can be spotted in binoculars, but most require at least a small telescope; the larger its aperture, the more galaxies you'll see and the brighter they'll appear. Here are just a few of the most interesting objects for deep-sky observers.



Markarian's Chain

Source: Wikipedia Commons ©Hewholooks

1 The Leo Triplet

Messier 65, Messier 66 and NGC 3628 make a lovely sight in just about any size of telescope. Since they are tightly knitted together, these three spiral galaxies are visible in the same field of view.

2 Messier 86

This is an unusual elliptical galaxy found in the heart of the Virgo Cluster. It's associated with a similar elliptical, Messier 84. Given its +8.9 magnitude, you'll need a telescope with a small to medium aperture to show an oval-shaped patch.

3 Markarian's Chain

Containing Messier 84 and Messier 86, this is a long, curved line of galaxies that forms part of the Virgo Cluster. You'll need a telescope with a large aperture to see the much fainter members.

4 Messier 100

This spiral is one of the largest and brightest objects in the Virgo Cluster, shining at +9.3. Its 'grand design' structure is difficult to pick out - you'll need a telescope with an eight-inch aperture and good conditions.

5 The Black Eye Galaxy (Messier 64)

It has a dark dust lane near its nucleus which gives rise to its nickname. A six-inch telescope will reveal the galaxy as a smooth oval, with its dark band becoming more obvious from a dark-sky site.

6 Messier 87

This supergiant elliptical galaxy in the Virgo Cluster is one of the most massive objects in our local universe. At magnitude +8.6, Messier 87 is readily observed using a small telescope.

The Black Eye Galaxy (Messier 64)

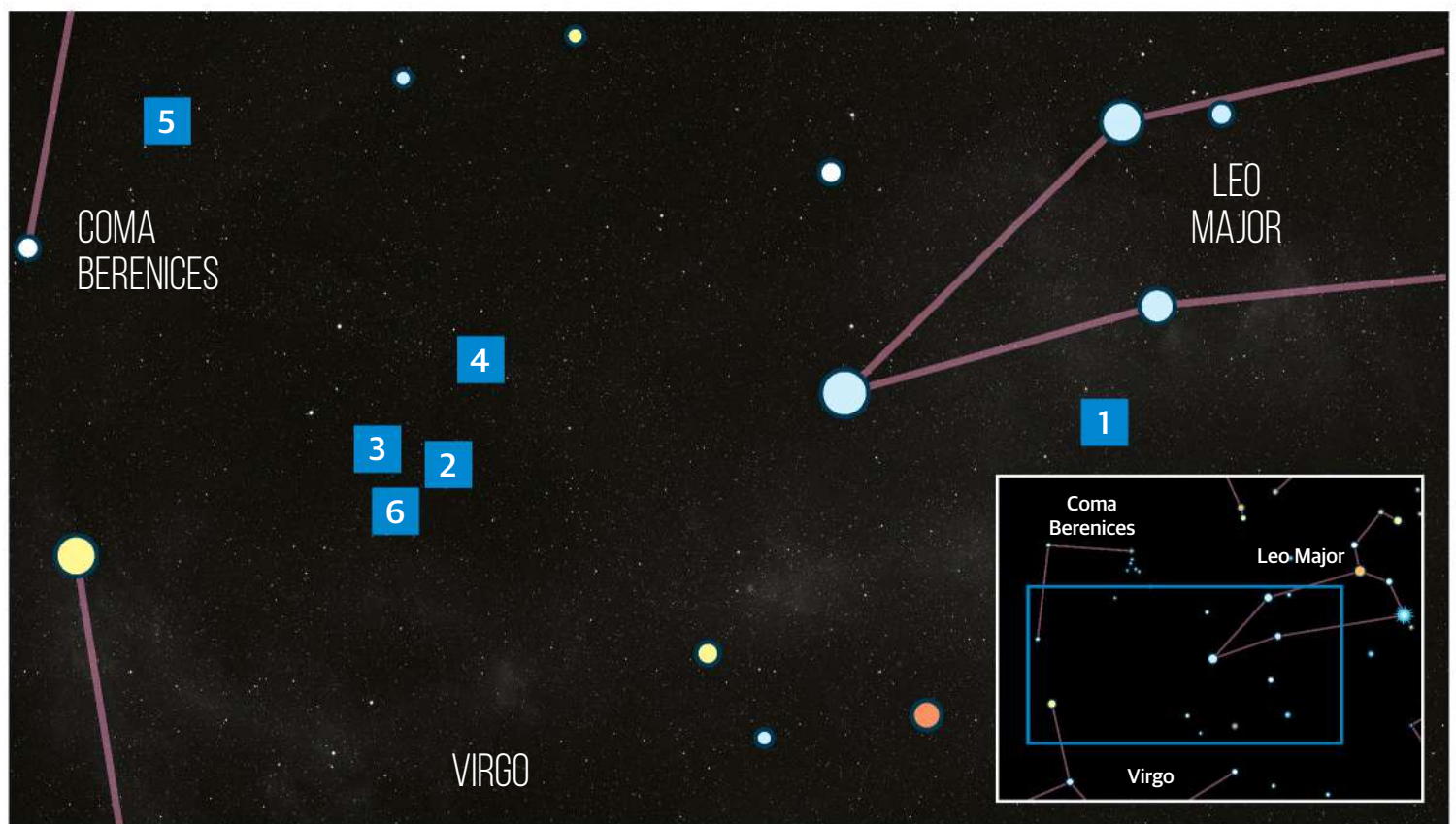
Source: Wikipedia Commons © NGC1535



Messier 87

© ISO

"SOME LARGER, BRIGHTER GALAXIES CAN BE SPOTTED IN BINOCULARS, BUT MOST REQUIRE AT LEAST A SMALL TELESCOPE"



THE NORTHERN HEMISPHERE

While the days are getting longer, there are still a variety of treasures if you're a night owl

A stunning array of star clusters grace the night sky of the Northern Hemisphere during May. The constellation of Hercules (the Hero) brings with it the beautiful Great Globular Cluster in Hercules (Messier 13) and Messier 92 for astronomers with telescopes with a small aperture. Meanwhile, the brightest star in the northern celestial hemisphere, Arcturus in Boötes, can be found in the south. For those who can't wait until the summer for a deluge of nebulae, the Cat's Eye Nebula (NGC 6543) in Draco (the Dragon) is an easy target with medium-power telescopes. Galaxies such as the Black Eye Galaxy (Messier 64) in Coma Berenices (Berenice's Hair) are also visible.

USING THE SKY CHART

This chart is for use at 22:00 mid-month and is set for 52° latitude.

- 1 Hold the chart above your head with the bottom of the page in front of you.
- 2 Face south and notice that north on the chart is behind you.
- 3 The constellations on the chart should now match what you see in the sky.



MAGNITUDES

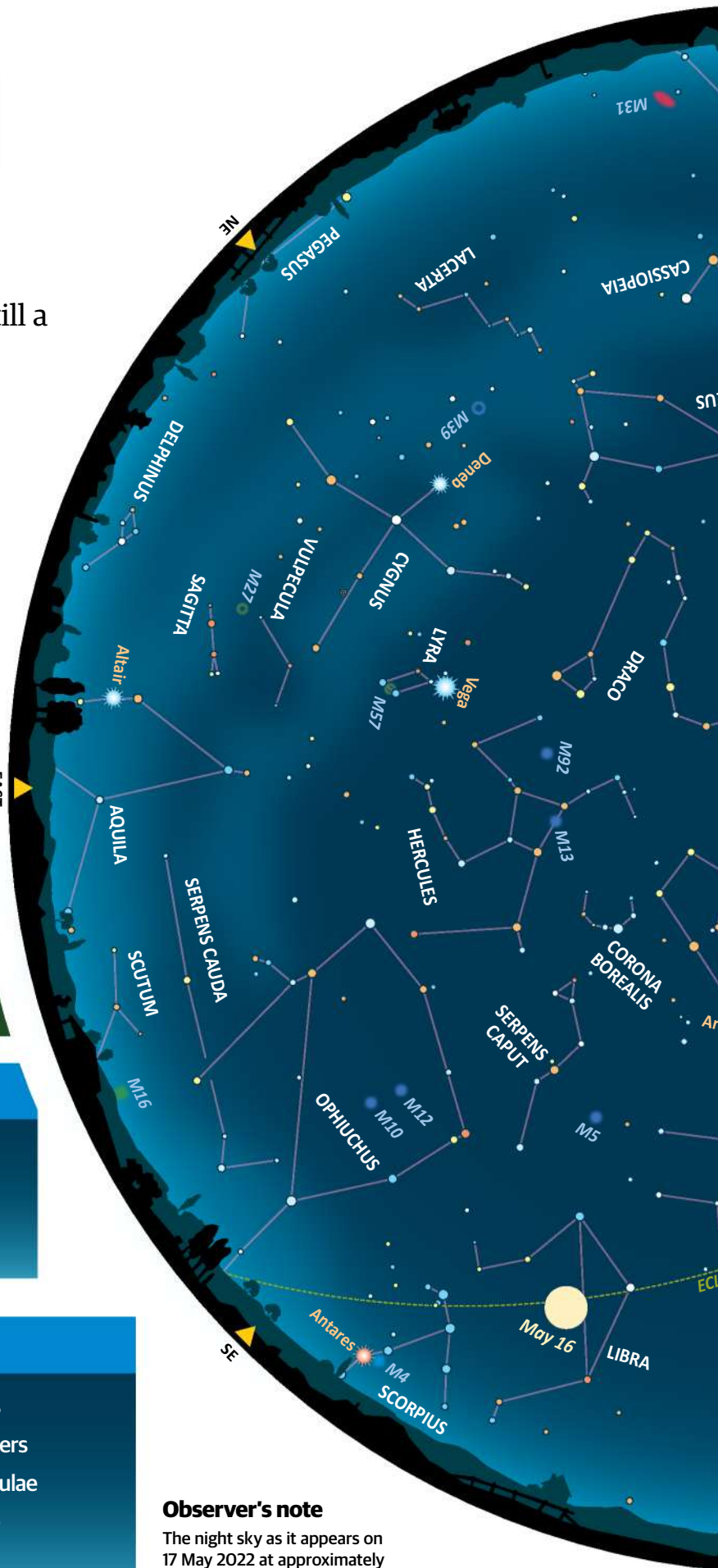
- ★ Sirius (-1.4)
- ★ -0.5 to 0.0
- ★ 0.0 to 0.5
- ★ 0.5 to 1.0
- ★ 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

SPECTRAL TYPES

- | | |
|-------|-----|
| ★ O-B | ★ G |
| ★ A | ★ K |
| ★ F | ★ M |

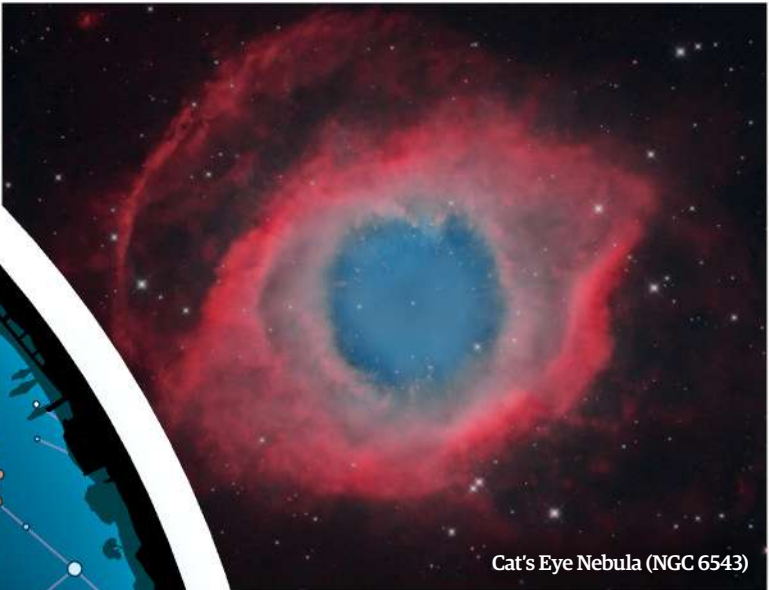
DEEP-SKY OBJECTS

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



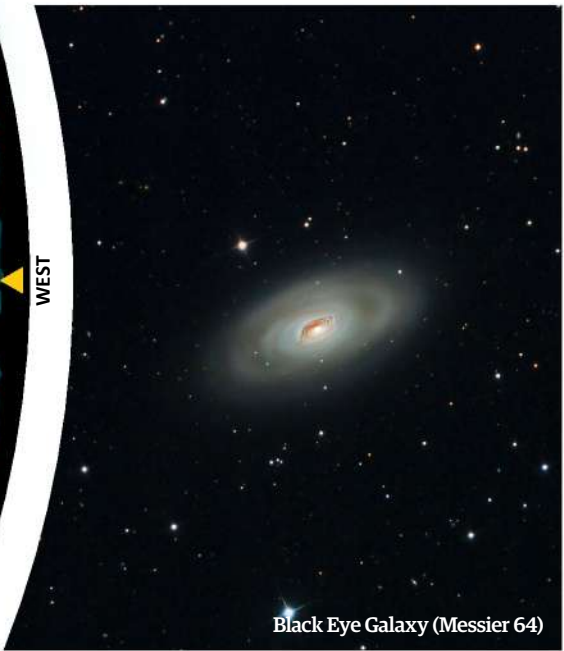
Observer's note

The night sky as it appears on 17 May 2022 at approximately 22:00 (BST)



Cat's Eye Nebula (NGC 6543)

© Getty



Black Eye Galaxy (Messier 64)

© Getty



Arcturus (Alpha Boötis)

© Getty

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to space@spaceanswers.com

Terry Hancock

Location: Michigan

Telescope: Takahashi FSQ-130

"My interest in astronomy began some 40 years ago in Australia. My first telescope was a 4.5-inch Newtonian, and I enjoyed many nights in the pollution-free, dark night skies of the hot Australian outback. It was often so dark that the Milky Way cast a shadow on the ground. The skies are mediocre in Western Michigan where I observe from these evenings. I pride myself in taking really long exposures of deep-sky objects and always try to maintain a natural look."

Above: The Elephant's Trunk Nebula (IC 1396)

Right: Jellyfish Nebula (IC 443)



Jeff Johnson**Location:** Las Cruces,
New Mexico**Telescope:** Takahashi FS-60C

"I have a long love of astronomy and have observed the night sky for many years with binoculars and a telescope from the age of ten. I did my first 'real' astrophotography in 1996 when I used a 35mm SLR camera to take photos of Comet Hyakutake. I took a tripod out into the desert here in Las Cruces and just experimented with exposures. Later I bought a ten-inch Dobsonian for viewing, and within a week was taking pictures through the eyepiece for fun. Within a few more weeks I knew I wanted to get serious with astroimaging."

Left:
Reflection
nebula
Messier 78

**Jaspal Chadha****Location:** London**Telescope:** Altair 150EDF and
Takahashi FSQ-106EDX

"I have been imaging for around two-and-a-half years now after spending years looking through various telescopes and eyepieces, where I enjoyed learning all about the objects in the night sky. After months of research and trial and error, I finally invested in a set-up that I thought would work for me. My biggest challenge has been to fend off the myths around imaging in light-polluted areas, as I live in London. I started out with DSLR astrophotography but now use a CCD to capture a wide range of night-sky targets."

Right: The
Tadpoles
Nebula
(IC 410)

Below:
Rosette Nebula
(NGC 2244)



REVIEW

CANON EOS 6D MARK II

Is this the perfect companion for enthusiast photographers looking to make their first break into the full-frame world?

Reviewed by Jacob Little

CAMERA ADVICE

Cost: £1,339.99 / \$1,399.99

From: Canon

Type: DSLR

Kit lens: N/A, sold with or without EF converter

Sensor: 26.2 megapixels

Lens mount: Canon EF

ISO range: 100 to 40,000

Viewfinder size/resolution: Optical viewfinder, 45-point autofocus

Video capability: 1080p

Weight: 725 grams

Size: 14.5 by 11.2 by 7.4 centimetres (5.7 by 4.4 by 2.9 inches)

Memory card type: Single SD

The original Canon EOS 6D saw the birth of a new breed of cameras - one that introduced beginner, enthusiast and amateur photographers to the idea of an accessible full-frame system. For those of us who balk at the idea of spending thousands of pounds on pro or semi-pro systems, the 6D offered an affordable alternative, and one that drew positive recognition from the industry and the photography community.

The Canon EOS 6D Mark II looks to update the original 6D with a far more modern specification list, and although the Mark II is in itself a few years old now, it's still a relevant and worthwhile consideration for many of us looking to get more serious about our picture taking.

Although there are some compromises to be made, the price alone makes the 6D Mark II an appealing prospect. As time marches on, the Canon EOS 6D Mark II finds itself sitting in an increasingly competitive market, so we'll see if it still matches up to modern-day demands by reviewing its design, functionality and image-making abilities. It still sits among our best cameras for astrophotography, especially as the price is relatively competitive.

First things first, out of the box the Canon 6D Mark II is noticeably heavier and bulkier if you're used to a compact or crop-sensor body. Although it's weatherproofed, we thought the slightly plastic feel of the body itself was disappointing,

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📷 LANDSCAPE PHOTOGRAPHY

👁️ SOLAR SYSTEM

🌀 DEEP SKY

Right: The 6D Mark II is a great introduction to full-frame cameras

Far right: The camera body is heavy - especially with large lenses - but sturdy





"IT STILL SITS AMONG OUR BEST CAMERAS FOR ASTROPHOTOGRAPHY, ESPECIALLY AS THE PRICE IS RELATIVELY COMPETITIVE"

but like many Canon products we were pleased to see well-rounded edges, a good hand grip and nicely rounded buttons. Overall, ergonomically the camera is easy to use, fits into the hand nicely and provides easy access to most controls.

At the rear of the camera there are buttons to change the autofocus mode, access the camera's menus and settings and switch it between still and movie modes. As with Canon's other full-frame offerings, there's a dial at the back which can be controlled using the outer thumbwheel - or more

conventionally by selecting left, right, up and down with the directional buttons. It takes a little getting used to, but in shooting mode it comes into its own, allowing far greater control of multiple settings at once. There's a start/stop button for movie recording and a 'Q' menu button that allows quick access to important shooting settings.

The key element to the rear of the camera is the variangled touchscreen, which we found worked well and allowed us to compose our images using more acute angles. It's a little dull when

exposed to bright sunlight, but overall the touch responsiveness is excellent and allows a good degree of manual control.

At the top of the camera there's a dedicated screen so you can see what the camera is set to at a glance, as well as a mode control selector on the top left. There's a little button at the top of the selector which needs to be depressed to change the camera's mode, which means it doesn't slip out of your chosen setting accidentally, but one to mention as it caught us out a couple of times - the selector won't move without the button being depressed. Overall, while it's nothing revolutionary, the Canon 6D Mark II's design and handling are pleasing and will suit most entry-level full-frame photographers.

Using the Canon 6D Mark II is much like using any other Canon product, and comparisons to the



crop-sensor 80D can't be avoided, as they have almost exactly the same rear panel and feel in the hand. One thing we did notice and enjoy was the speed of operation. Even in live mode, everything turns on, boots up and is ready to go in an instant, which greatly assists in getting those momentary or easy-to-miss shots. As you'd expect on a full-frame system, the large viewfinder makes it easy to compose shots. Although it does feel bulky, the weight has been nicely trimmed compared to the 5D, and it feels like an easy unit to deal with. We tested the system with Canon's 24-105mm lens, which did add considerable weight, but users of 50mm or smaller prime lenses will certainly notice the weight reduction.

Dual Pixel technology means that the Live View works well in most conditions, although we did find it a little hard to see in direct sunlight. It feels good to use and is very responsive, though, which twinned with its variangle articulating ability means shooting from the hip or at strange angles is perfectly doable.

Although we thought the dial at the rear of the camera was easy to use, the inner directional buttons are difficult and sometimes fiddly - we thought Canon would have been best to do without them and opt for a simpler system like the joystick on its 5D. This is especially relevant if you want to manually adjust focus through the viewfinder, for example. That being said, we thought there was an emerging theme here: Canon has to find a way of differentiating the 6D Mark II as being the 'lower spec' entry-level DSLR.

As you'd expect for a camera at this level, there's built-in Wi-Fi, near-field communication and bluetooth, which makes connecting and transferring images to smartphones or tablets easy. When we got down to business, we liked how the

FOR

- ➕ Reassuring colour reproduction
- ➕ Great introduction to full-frame
- ➕ Good backup option for pros
- ➕ Good low-light performance

AGAINST

- ➖ Doesn't break any exciting new ground; performance could be better
- ➖ Doesn't necessarily match up to existing full-frame Canon products
- ➖ Autofocus is outshone by competitors
- ➖ Full-frame system may be outgrown quickly

Canon 6D Mark II performed. While it doesn't do anything really worth writing home about, we were impressed with its ability to keep up with the demands of the modern shooter. Five years on from its release, the autofocus is perhaps lacking a little, but in most other respects it performs well.

With no settings altered and straight to auto mode, JPG images at the highest resolution were pleasing when it comes to colour rendition and accuracy, although we found that like many other Canon systems they had a slightly overprocessed feel to them and appear a bit on the sharp side. The camera worked very well in areas of subtle contrast, but out in the sunshine was where performance cracks started to appear.

Much has been made of Canon's decision not to put the at-the-time latest sensor into the 6D Mark

II, as used on the 5D Mark IV and EOS 80D - a differentiation of price must have been the primary concern here. In areas of high contrast, at lower ISO settings there's a noticeable diminishing of dynamic range - the ratio difference between the brightest and darkest tones in an image - which means that boosted photos can start to appear grainy and noisy, especially where the lower tones have been increased. Because of this, we'd suggest that experienced photographers look elsewhere. If you know what you're doing in post-processing, you may find the lack of range frustrating.

That being said, with what the camera is setting out to do, how much did we worry about this? The answer is not a lot, to be honest, as in most other respects we enjoyed what the camera had to offer, and we expect most other enthusiasts or amateur photographers would do too. For newcomers to the full-frame world, the possibilities it opens up are exciting and go far beyond worrying about dynamic range. With regards to the wider angled, lower light astrophotography sphere, low-light performance is good and the quiet shutter and subtle operation would be suitable for those getting into nighttime photography.

There's no 4K with the Canon 6D Mark II, which makes it difficult to recommend for today's filmmakers, but the Live View does work well should you wish to start filming. One word on the autofocus system, though. We found it to be perfectly dependable in stable environments and think it'd be fine for low-light situations, but it struggled a little more with moving subjects and the subject tracking is pretty average - and even more so in Live View. If you're a budding sports or events photographer, you may want to look elsewhere or keep the 6D Mark II as a backup.

With its increased megapixel count, faster operation and generally better handling, the Canon EOS 6D Mark II is a vast improvement over the ageing original 6D and has many things to recommend. The image quality is excellent, and in the right hands it's a very capable machine. Although it's not the most exciting camera development and there's still room for improvement, we found it hard not to enjoy using it despite its shortcomings in terms of autofocus and lack of dynamic range. If we put those to one side for a moment, for people getting into the full-frame world for the first time, it's an exciting prospect to be faced with a far more advanced and pleasing style of image taking.

In the years since the 6D Mark II was released, there have been improvements in the entry-level full-frame market, so it's worth mentioning that you may want to do some research. That's not to say the 6D Mark II is a bad camera - far from it - but it would pay to do some testing of other systems to ensure that with this one you're getting the most from your hard-earned cash.

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SPACE EXPLORATION

In this new special bookazine from the makers of **All About Space** and **Space.com**, we answer the question of what's out there in the universe. Rewind the clock to the 1950s and relive the first brave forays into space exploration with the likes of Sputnik before moving into the Space Age. Look back on iconic white-knuckle missions such as the Apollo 11 Moon landing, with special insight from Buzz Aldrin. We'll also uncover some of the universe's most beautiful sights, thanks to Hubble, and look at the intrepid Voyager probes as they journey farther into interstellar space. We'll examine the technology that drives space exploration, such as spacesuits, rocket science and more, before touching on the more current innovations in the field today, as well as our fascination with Mars.

GUIDE TO THE SOLAR SYSTEM

Our Solar System is one of the most interesting places in the galaxy. It's the only place we know of that harbours life, on one small planet in the habitable zone of its star. But our planetary neighbours are interesting too. In this complete guide to our circumstellar neighbourhood, you'll discover everything you need to know about them, from the warm, rocky world of Mercury to the distant orbit of the object scientists call Farfarout. You'll discover a wealth of worlds - not just the eight main planets, but some of the moons that orbit them and the dwarf planets that swing through the outer reaches of trans-Neptunian space. The planets and moons of our Solar System will be some of the first places humans will explore when we finally venture beyond our own Earth and Moon.

BOOK OF MARS

When this bookazine first went to press, NASA had deployed the very first instrument from its InSight mission onto the surface of Mars. InSight, a robotic lander, is tasked with examining the interior geology of the Red Planet, looking back in time to tell us how Mars, and by extension the other rocky planets, formed. The history of Mars is intrinsically bound up with that of Earth - some scientists even think that the original building blocks of life came from there. The Red Planet is finally being persuaded to give up some of its secrets. We'll reveal what scientists know so far about the planet that has captured the human imagination for centuries, examine the theories that may help us understand it further and explore how one day we could make it into another human home.

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1



FOR GAMERS

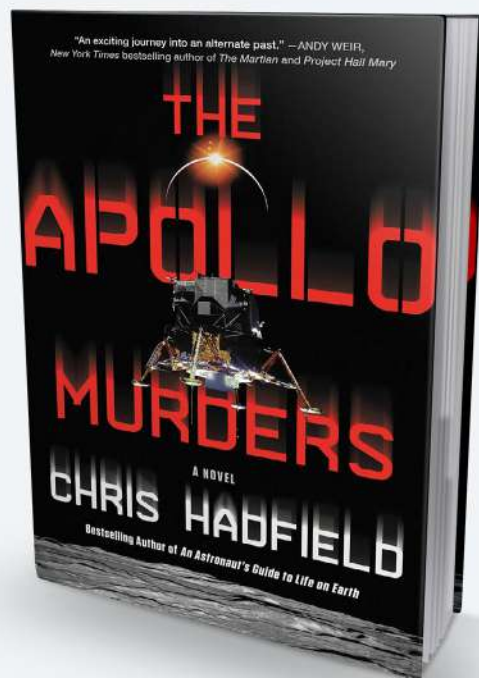
SPACE COMMANDER: WAR AND TRADE

Cost: Free

From: Steam

1 True space exploration on a grand scale can be tough to pull off, so learning that a free-to-play game has done it is pretty impressive. *Space Commander: War and Trade* is a callback to other great titles in the genre. Your main goal is to explore the universe, make money and keep upgrading your ships until you become the best pilot in the galaxy. The game does feature ads, but they're not as intrusive as many similar games. It's also entirely possible to enjoy the entire single-player campaign without investing any money at all.

2



FOR BOOKWORMS

THE APOLLO MURDERS

Cost: £20 / \$28

From: Amazon

2 Astronaut Chris Hadfield looked back in time and saw the makings of a nail-biting Cold War thriller set within the real events of 1973. With a creative eye on the Moon in his first dive into fiction, *The Apollo Murders* is a rousing adventure placed amid the tense days of the Space Race following America's lunar landings. The alternative history is set in 1973, when NASA launches a final top-secret mission to investigate a crewed Soviet space station called Almaz. The clandestine flight continues to the Moon as both Russian and American crews target a huge bounty hidden on the lunar surface.

3



FOR ASTROPHOTOGRAPHERS

HAIDA HD4635 LENS HEATER AND ANTI-FOG BELT

Cost: £27.21 / \$20

From: Amazon

3 This anti-fog belt is incredibly easy to install thanks to its simple Velcro design. It's also made from graphene, allowing the belt to heat up quickly so you can rescue your lens from fog in the nick of time. Like most lens heaters, it comes with a USB port, which is best attached to some kind of external power bank, and has three 'heat' settings for you to try out. A little LED light indicates that it's on and working - this could damage your night vision while you're out taking astrophotos, so it's best to find a way to shield it.



5



4



"THIS NORTHERN LIGHTS PROJECTOR IS COMPATIBLE WITH ALL ANDROID AND IOS SMARTPHONES"



6

FOR YOUR HOME

AURORA BOREALIS NORTHERN LIGHTS STAR PROJECTOR

Cost: £171 / \$219.97

From: encalife.com

4 You get to choose from 16.7 million aurora colours and you get to do it with ease by controlling it with your smartphone. This northern lights projector is compatible with all Android and iOS smartphones, and it allows you to save a combination of stars, the Moon and aurora borealis to suit your mood. The projector also includes the ability to turn on music to change and suit the mood.

FOR FUN

LEGO NASA SPACE SHUTTLE DISCOVERY

Cost: £159.99 / \$199.99

From: LEGO

5 There's no denying that this LEGO Space Shuttle Discovery is one of the best LEGO space sets you can get your hands on right now. It's an authentic recreation of NASA's real Discovery shuttle, featuring realistic elements such as an opening payload bay, retractable landing gear and five seats for the crew. Unfortunately, you'll have to use your imagination there since this set doesn't come with minifigures, but it's a small price to pay for something that's otherwise so detailed. It also includes a model of Hubble which can be stowed in the payload bay.

FOR STARGAZERS

STELLARIUM MOBILE PLUS

Cost: £14.49 / \$19.99 (Play Store) £11.99 / \$13.99 (iOS)

From: Stellarium

6 The mobile version of the well-known desktop app is a database that contains more stars than any other app, but not as many asteroids as Sky Safari. It isn't as polished as that app either, though the way it pinpoints your position using GPS and displays the sky above you is spot on - the sky you see displayed on your phone will be fairly similar to the real sky above you. You can locate and label your favourite constellations and planets, track satellites as they traverse the sky above and access lore and stats about the stars and planets you select, including stories from different cultures.

LYMAN SPITZER

The man who helped us see the universe in a new way

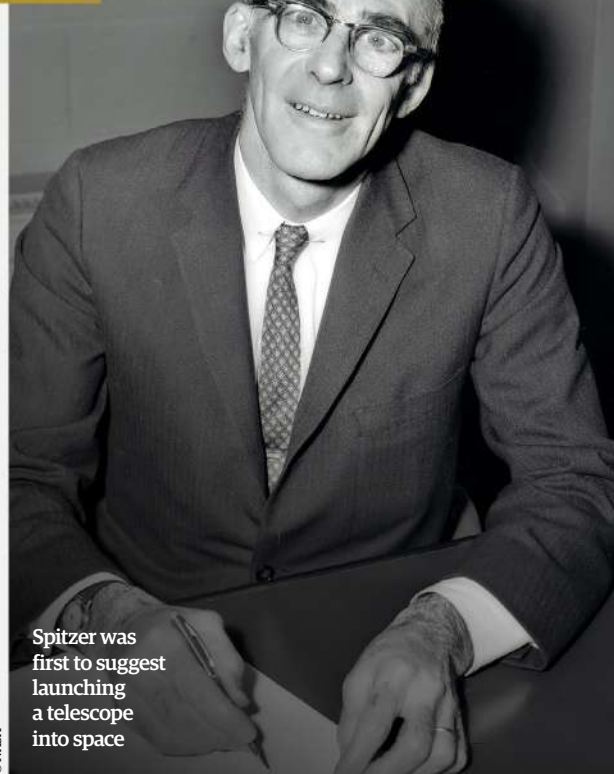
Born on 26 June 1914 in Toledo, Ohio, Spitzer may have inherited his eager and curious mind from his ancestor Eli Whitney, the inventor of the cotton gin, a machine that revolutionised the cotton industry. A natural and passionate learner, Spitzer earned a place at Yale University, where he studied physics. He also spent a year studying abroad at Cambridge University before finally entering Princeton, gaining a masters degree and a doctorate in astrophysics under the mentorship of the famous astronomer Henry Norris Russell.

Spitzer took up a teaching position at Yale in 1939. When World War II broke out, he engaged in underwater sound research as part of the team that developed sonar. It was when he returned to Yale after the war was over that he had the idea that would place him firmly in the history books. In 1946 Spitzer conceived the notion of putting a telescope in outer space, theorising that if the device was in space it would bypass any issues of blurring as a result of being in our atmosphere, thereby producing clearer images than any terrestrial telescope could hope to achieve. He recorded these ideas in his paper *Astronomical Advantages of an Extra-Terrestrial Observatory*.

Spitzer's proposition was revolutionary for its time. It was over a decade before the first satellite was launched into space and 12 years before the creation of NASA. Undeterred by the opposition, Spitzer was dedicated to his space telescope and worked for the next 50 years of his life trying to make his dream a reality.

The professor's excellence in astrophysics continued to attract attention. In 1947, aged just 33 years old, he was appointed chairman of Princeton University's astrophysical sciences department as well as the director of the university's observatory. Under his leadership, it became an important research facility. He fervently studied the interstellar medium and star formation, and his work in this field has led many to hail him as the founder of the study of the interstellar medium.

Spitzer added to his accolades by being appointed president of the American Astronomical Society in 1960. He was lucky enough to be able to watch as the space program developed and his own concept of putting telescopes in space came closer to



© NASA

Spitzer was first to suggest launching a telescope into space

reality than ever before. In 1962 he designed an observatory that could orbit Earth. This very same observatory later became the Copernicus satellite, used by NASA between 1972 and 1981. While many of his peers were opposed to the cost of Spitzer's space telescope, he worked tirelessly to convince the academic community and US Congress that it was a worthwhile endeavour, and he finally achieved it in 1968 with the Orbiting Astronomical Observatory.

Although he was decorated with awards for his achievements, Spitzer didn't slow down, managing to convince both NASA and Congress to begin work on the Hubble Space Telescope in 1975. Because of Spitzer's efforts, Congress agreed to fund the construction of the telescope in 1977. In 1990, 44 years after Spitzer first envisioned the existence of a telescope in space, the Hubble Space Telescope was launched. To this day Spitzer's creation has delivered stunning and breathtaking images that were previously unfathomable, helping us to understand space and leading to countless new discoveries.

Lyman Spitzer worked tirelessly, even up to the day he died: when he passed away suddenly on 31 March 1997, aged 82, he had just finished discussing exciting new ideas with his colleagues and studying the results from the Hubble Space Telescope. In 2003 NASA launched a brand-new observatory into Earth's orbit, which the agency named the Spitzer Space Telescope in honour of the man whose vision and determination made it all possible.

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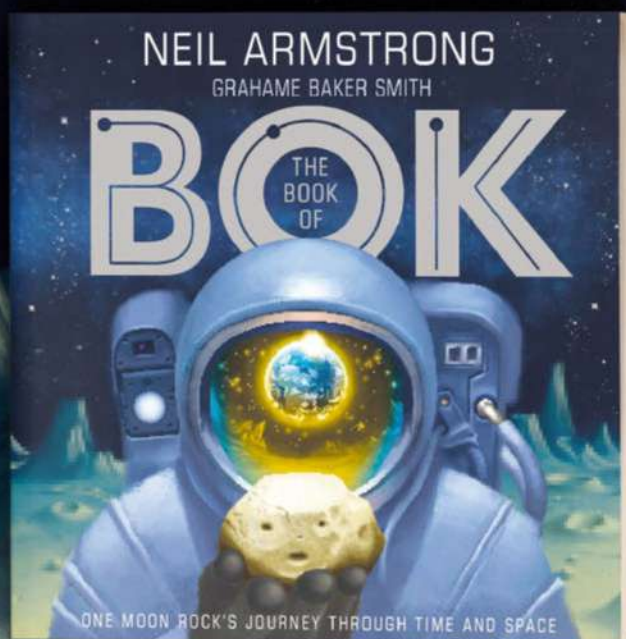
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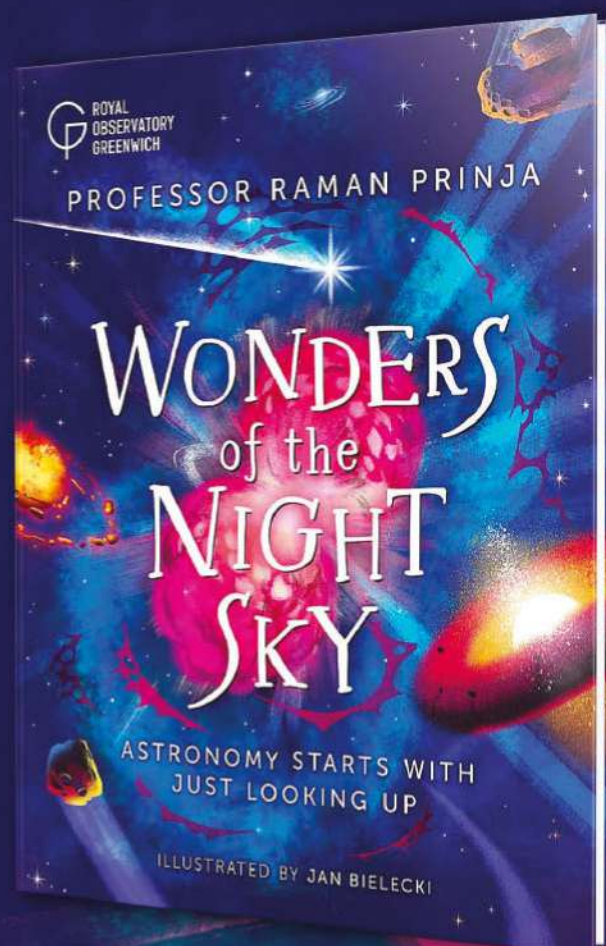
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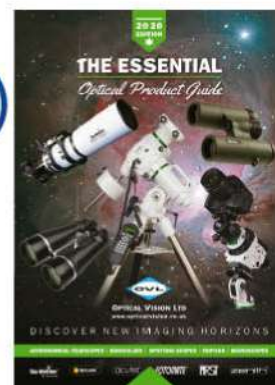
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